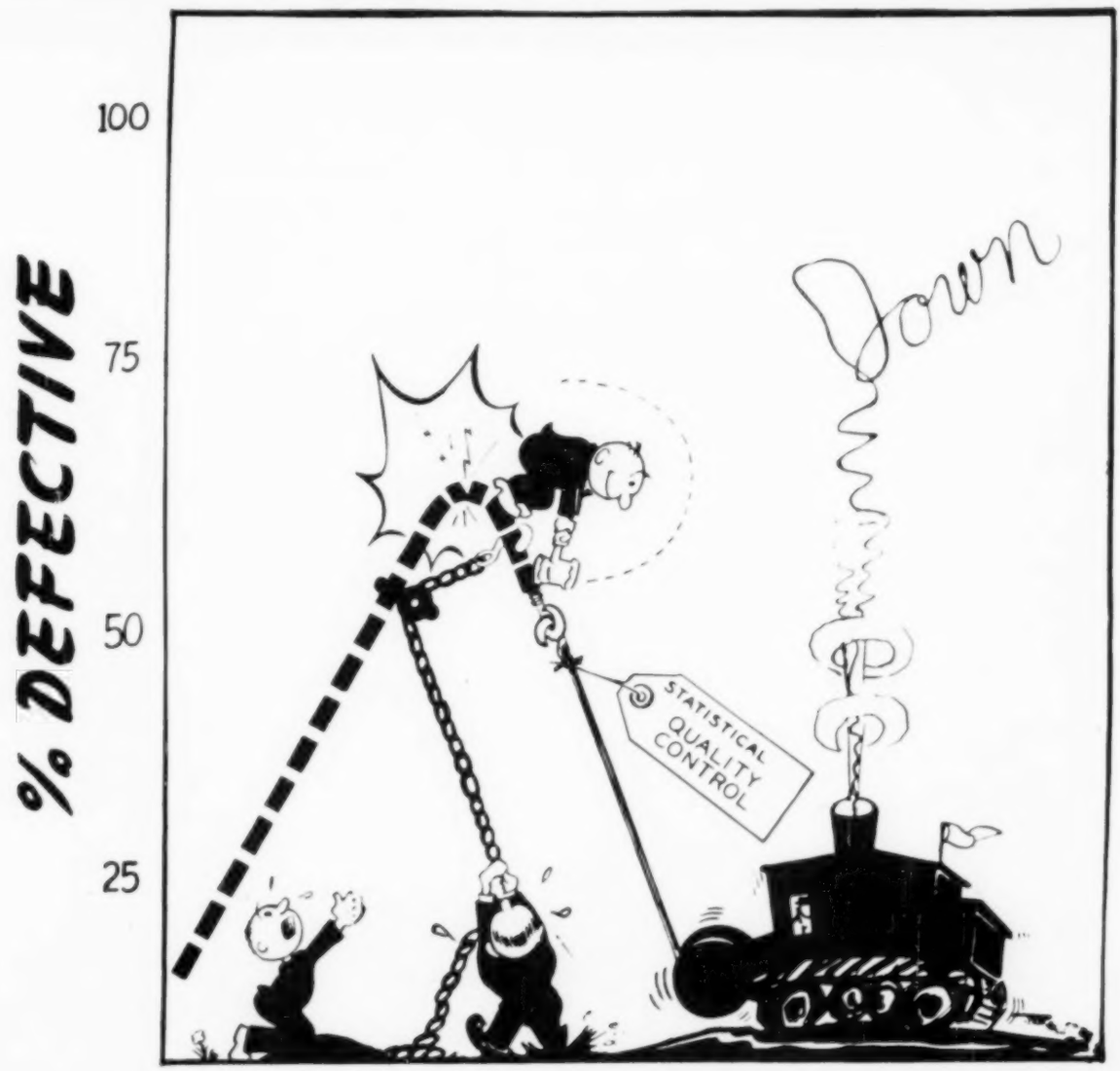
Industrial QUALITY CONTROL

VOL. IV MAY, 1948 NO. 6



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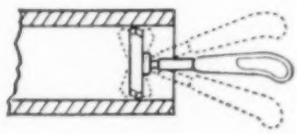

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WRITE FOR BULLETIN

STANDARD GAGE CO., INC., Poughkeepsie, N.Y.

HISTORICAL NOTE

Contributed by

C. C. VAN VECHTEN

Navy Department

Bureau of Ordnance

Walter Shewhart is rightfully acknowledged to be the father of Modern Statistical Quality Control, and indeed it is his child which has become the husky youngster that seems on the verge of something approaching a revolution in production methods. However, few ideas survive the first time they are offered, and it would be surprising if Shewhart's surviving idea had not been preceded by earlier ones that died. The following example of a technique clearly entitled to be called Statistical Quality Control has come to the writer's attention; there may be others.

In 1911-12 a M. Provost was in charge of the Havre factory of the French (government) Tobacco Monopoly. He was engaged in writing a "Magistral Dissertation," and he was faced with a problem. Customers complained when their packages of tobacco were underweight, and the monopoly lost money when they were overweight. Starting with the assumption of the Normal (Gaussian) Curve, which is basic to all our statistical quality control, Provost obtained **average** weights of individual worker's daily output (hand weighed) by an ingenious method of weighting the total daily output for all workers. **Dispersion** was obtained from small samples taken at random. An incentive was paid for keeping the average right and the dispersion low. Results were: (1) a great reduction in the amount of inspection, (2) practical elimination of underweight packages, and (3) an annual saving of 1,000,000 kg of tobacco (from overweights). Apparently Provost's plan was successful even though his successors seem to have let the idea die, and he himself went into other fields.

Provost's dissertation "Memorial des Manufacture de'l'Etat" is not, to the best of the writer's knowledge, available in the United States. A summary of it, however, is available in L. Blondeaux "Le Tabac et les Alumettes" in the Journal de la Societe de Statistique de Paris, 1938, on pp. 157-8.

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The cover picture for this issue is a reproduction of a slide used in a talk given to the Syracuse Section by Mr. H. Paul Nelligan, President of the Easy Washing Machine Company. It was submitted by Edward A. Reynolds.

Quality Control Leads the Way*

A. E. R. WESTMAN

DIRECTOR, DEPARTMENT OF CHEMISTRY, ONTARIO RESEARCH FOUNDATION

GENERAL THEME

The general theme of the Second Annual Convention of the American Society for Quality Control and the Fourth Annual Rochester Clinic is "Quality Control in the Coming Buyer's Market." This theme constitutes a timely recognition of the fact that the seller's market which has been in effect for many years cannot continue indefinitely. Already there are indications that the turning point may have been reached.

In a seller's market there is a persistent, unsatisfied demand for all the products that industry can provide, and it is only natural that the emphasis should tend to shift from the normal, economic objective of achieving adequate quality at minimum cost to the abnormal and, in the end, uneconomic objective of maximum quantity at whatever cost expediency appears to justify. The customer pressing for deliveries is not inclined to be very critical of the cost, quality, or uniformity of the products offered; the manufacturer is inclined to tolerate practices and develop habits of thought which, if carried over into a buyer's market, will prove to be severe handicaps.

The coming buyer's market will likely constitute a more severe challenge to manufacturing efficiency than those we have known in the past, because the customer will have at his disposal all the statistical and quality control techniques for specifying and enforcing a quality standard which have been developed over a period of years. Even the domestic consumer will be in a much better position to insist on, and secure, a definite standard of quality.

The papers given at the general sessions and luncheons of the convention dealt with the task of showing in detail how statistical quality control can render effective service to Management, Sales, Engineering, Purchasing, Manufacturing, and Inspection in meeting the problems that will be created by the coming buyer's market.

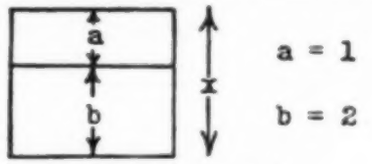
This paper will endeavour to provide an understanding of some of the principles that underlie statistical quality control, and to show by reference to applications in the processing and other industries how statistical quality control leads the way not only to greater industrial efficiency, but also to the application of other statistical techniques of a more advanced character.

STATISTICAL QUALITY CONTROL†

The majority of statistical quality control applications have been based on the use of two statistical techniques, exemplified by the control chart and the sampling inspection plan. In common with other statistical methods, these techniques enable one to deal with materials, processes, and other quantities which are essentially variable in character, and it is for this reason that they have made outstanding contributions to industrial efficiency. They provide positive indications for action and enable quantitative judgments to be reached in situations in which the important factors are variable in character.

It will be appropriate at this point to take a little time to explain what is involved in statistical reasoning, using a control chart as an illustration.

First let us see how a statistical problem differs from the exact problems which we learned to solve in school. To take a very simple case, consider the two problems outlined in Figures 1 and 2. We have all heard of, or have used, standard gauge blocks. These blocks are so accurate in length that for ordinary engineering purposes we may consider that a 1-inch gauge block is exactly one inch in length. Now the problem illustrated in Figure 1 is this. If one takes a 1-inch gauge block and a 2-inch gauge block and "wrings" them together in approved fashion, what will be the overall length of the assembly? The traditional answer is, of course, that 1 plus 2 equals 3, and therefore the overall length will be 3 inches. This sort of calculation is exactly what most scientists and engineers have been trained to do.

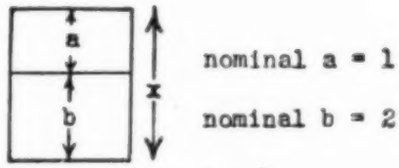


$$x = a + b$$

$$= 1 + 2$$

$$= 3$$

FIGURE 1 — GAUGE BLOCKS



$$x = a + b$$

$$= 1 + 2$$

$$= 3$$

$$\therefore \text{nominal } x = 3$$

FIGURE 2 — MACHINE PARTS

*Presented at the Second Annual Convention of the American Society for Quality Control, Rochester, N. Y., February 16, 1948.

†Some of the text and diagrams in this and subsequent sections of this paper were taken from previous publications by the author in Canadian Metals and Metallurgical Industries, Canadian Chemistry and Process Industries and the ASTM Bulletin and due acknowledgment is made to these publications. For detail see references (1), (2) and (3).

Note that it starts from certainties and admits no possibility of failure. We can predict the outcome of an individual experiment with certainty.

This kind of "gauge block" reasoning would be quite adequate if we lived in a "gauge block" world where raw materials never varied in quality, processes always functioned in exactly the same fashion, and all products from a given process were identical. Such a world is impossible of attainment and, even if it were, would be highly uneconomic.

Contrast this with the second problem shown in Figure 2. Here two metal blocks nominally 1 inch and 2 inches in length have been picked at random from the current output of two machines and assembled end to end. Since such machines do not operate with "gauge block" precision, we really do not know **a** or **b** and the calculation as shown is misleading in that, if the variation in **a** and **b** introduced by the machines is of the usual type, "nominal" will have a different meaning when applied to x than when applied to **a** or **b**, insofar as it is intended to specify the amount of variation to be expected. Also, one must face the fact that the performance of such an assembly will depend on its actual rather than its nominal thickness. The writer recalls some badly-needed military trucks rolling off a production line during the last war, and then "seizing up" within the first fifty miles because the nominal clearance between piston and cylinder, which was counted on to prevent seizure during the breaking-in period, in point of fact hardly existed.

In this second type of problem. we can no longer predict the length of an individual assembly with certainty, and the exact methods we learned at school no longer apply.

At first sight, a situation in which individual values are unpredictable may appear hopeless, but it is in just such situations that the control chart technique can be applied.

To illustrate this, consider the situation shown in control chart form in Figure 3.

Four dice were thrown repeatedly and the total number of pips showing at each throw was recorded as one observation. This

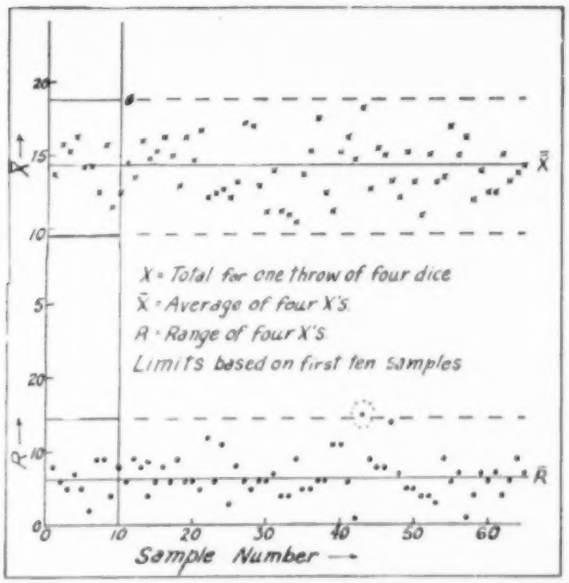


FIGURE 3 — CONTROL CHART FOR THROWS OF FOUR DICE

number could range from 4 to 24 inclusive. After 40 throws had been made, the observations were grouped into ten groups of 4 and the average and range (highest minus lowest) for each of the ten groups plotted in chronological order in Figure 3, the averages, $\overline{X}$, in the upper part and the ranges, R, in the lower, the latter serving as a measure of variation. Control chart limits were computed by the usual methods and were extended across the diagram as shown by the broken lines. Such limits provide a test for control, since under controlled conditions the great majority (usually more than 99 percent) of the points should fall within the limits. The experiment was then continued until 260 throws had been made and the remaining points plotted as shown in the figure. It will be observed that all but one point fell within the limits.

Here, clearly, is a case in which individual observations are unpredictable, since we do not know with certainty in advance of a throw whether we shall get a 4 or 24 or some value in between, and yet we have control with respect to time both in the average values and in the variabilities observed at different times.

It is also important to note that the variability exhibited by the points in Figure 3 is that inherent in throws of four dice, and no effort on the part of the experimenter will reduce this variation as long as four dice are used and thrown in an unbiased manner, i.e. as long as the process is essentially unchanged.

The control exhibited by Figure 3 is precisely the kind of control which is our objective when control charts are applied in industry. Variation is reduced to that which can be attributed to chance causes, and a stability is achieved which makes it possible to predict what the process will do in the future even though it is impossible to predict the values of individual items. In achieving this control, extraneous causes of variation are detected and removed, resulting in a striking improvement in quality and uniformity.

That such control can be brought about in industry has been shown in numerous instances in the past twenty years, in which it has been found possible to make machines and complicated manufacturing processes exhibit the kind of control shown by the dice data in Figure 3.

Figure 4, which shows a record of the daily percentage of defective tank shoes produced by a large foundry using a complicated process during World War II, will serve as an illustration at this point. This example will be discussed in more detail later.

First let us consider a less complicated process, that of rolling aluminum strip to specified thickness.

QUALITY CONTROL OF ALUMINUM STRIP

A Canadian manufacturer of aluminum goods received wide aluminum strip in semi-fabricated condition, rolled it by a series of successive passes to a nominal gauge of .0185 inch, and then subjected it to a slitting operation. The narrow strip from this operation was drawn into latex cups by a sub-contractor. The specification was .0200 inch maximum and .0160 inch minimum.

A wide variation in gauge existed, and difficulty was experienced in drawing, especially when the gauge approached the lower specification limit. All strip under this limit was scrapped, but over-gauge material was used. Consequently, there was a tendency to operate with a mean value practically at the upper specification limit.

Final inspection was performed at the slitting operation, which was the first point at which the inspector could check the thickness both across the width and along the length of a coil.

A quality control investigation disclosed the following situation:

(1) approximately two days elapsed from the time the metal was finish rolled until the inspection data were available;

(2) variation in thickness across the width of a strip at the mill was random and negligible.

Inspection was transferred from the slitter to the mill where control charts would act as a means of control rather than an historical record. The inspector then gauged each coil by averaging readings at four points along one edge. Average thickness and range for subgroups of two coils were plotted on a control chart similar to that shown in Figure 3. The actions to be taken when points went out of control were specified. Possible variation in thickness across the width was checked for one coil in twenty at the slitter.

In this way it was possible to secure and maintain a state of control with a center line at .0180 inch, thus saving approximately 10 percent of the aluminum. With practically no strip below .0170 inch, the scrap produced in the subcontractors plant was reduced from an erratic and high level to a controlled 0.5 percent. All this was accomplished without increasing production costs.

QUALITY CONTROL IN A RADIATOR PLANT

As an example of an application of control charts to a large-scale mass production, the case of an American radiator plant may be cited. This plant is operating on a two-shift basis, and some 600 control charts are posted twice each day. Any necessary data beyond that available through the normal inspection procedure is gathered by twelve quality control men on the production lines. Posting takes about two-thirds of the time of two clerks and one coordinator. This may sound like an over-investment in quality control, but actually the savings through reduction in leaks requiring final repair is more than ten times the cost of the quality control program.

QUALITY CONTROL OF TANK SHOES

In the two cases so far considered, the operations have been largely mechanical in nature. However, many striking applications have been made in the metallurgical, chemical, and process industries. In these industries, the quality of the final product depends on a very large number of factors or variables starting with the properties of the raw materials and their proportions and including the characteristics of all the various processing steps right up through the finishing operations. Frequently, workmanship is a most important factor. Under these conditions it might be thought impossible to achieve the kind of control we have been discussing, but actually it has been found possible in numerous instances.

An example which will illustrate many of the principles involved is that of the control of the quality of manganese steel tank shoes at Electric Steels at Cap de la Madeleine near Three Rivers, Quebec, during World War II. The net result of this quality control program has already been shown in Figure 4. The difference between the situation shown at the left and right-hand side of this diagram was the result of some months of effort on the part of the operating and quality control staff.

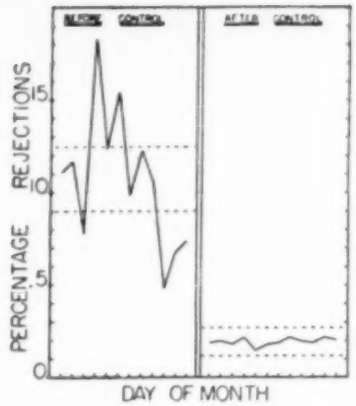


FIGURE 4 — QUALITY CONTROL APPLIED TO TANK SHOE PRODUCTION

The tank shoes produced at Electric Steels were small castings weighing approximately 20 pounds. They were made from high manganese steel which has a high coefficient of expansion and other properties which made it a difficult material to cast. This difficulty was enhanced by the intricacy of the design. The plant had been constructed specifically for making 500-pound cast steel bombs, and did not lend itself readily to tank shoe manufacture.

Approximately four-ton heats of metal were melted down and refined in electric furnaces, tapped into a ladle, and then cast in a triple row of flasks or moulds assembled for the purpose. When the castings had solidified, they were dumped from the moulds, gates and feed heads were removed, and then the castings were heat-treated in continuous furnaces, quenched in water, tumbled with coarse shot, ground, drifted, and painted. At various stages in the process they were subjected to visual inspection and any defective shoes were scrapped. A final 100 percent inspection was made by Government inspectors before the shoes were assembled in belts.

The moulds used in casting contained core sand, facing sand, and moulding sand, each type being prepared in separate batch mixers. Approximately 25 moulds were required for a heat, each mould holding eight shoes.

The progress of one heat through the plant marked one complete cycle of operations in the melting, casting, and mould-making departments, twenty-five new moulds arriving at the casting station in time for the next heat to be poured. Thus, each heat would correspond to one throw of the dice used in securing the data for Figure 3.

About 15 heats were tapped in each 24 hours, or an average of 5 heats per shift. About 200 shoes were cast per heat, so the daily production was about 3000 shoes.

Quality control charts were set up both on a shift basis and on an individual heat basis for some 40 process variables covering chemical analysis, sand properties, melting and pouring practice, etc., and for eight product qualities. The charts for individual heats were mounted on the wall of the control room in such a way that all data pertaining to a particular heat were plotted on one vertical line. In this way, as production continued, the charts were extended to the right and the whole history of past operations for several months was displayed. Approximately 100 charts were posted.

Once a measure of control was achieved, an effort was made to adjust all variables to their optimum center line values using a rather simple statistical technique which proved to be very effective.

A story could be told with regard to practically all the fifty or so factors investigated in the above fashion, but one of them, the silicon content of the steel, will serve to illustrate the value of the quality control approach.

The specification on silicon was 1.00 percent maximum. Since one or two heats had been rejected for exceeding this amount and the silicon content was difficult to control, a low target for silicon had been adopted. The control charts showed that much better control of silicon was possible than was being obtained and, in cooperation with the analytical laboratory, methods were evolved by which silicon content was brought into control. Other studies showed that a high silicon content would appreciably reduce the risk of making defective shoes. With control assured, it was possible to raise the target to 0.8 percent silicon with an upper control limit at 1.05 percent. In this way a considerable gain in quality was obtained without increasing the risk of rejection for high silicon content.

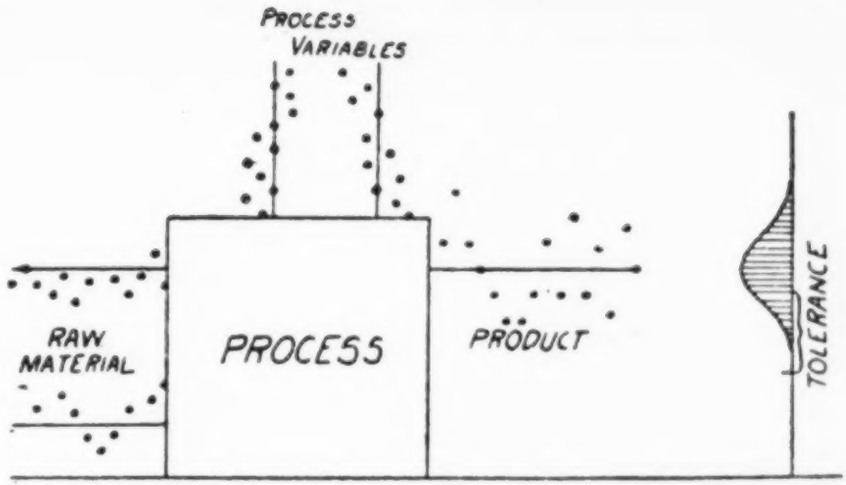


FIGURE 5 — DIAGRAM OF AN UNCONTROLLED PROCESS

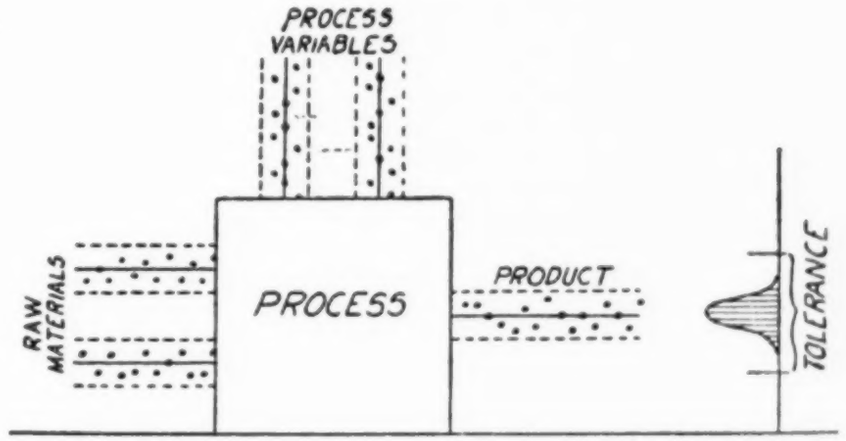


FIGURE 6 — DIAGRAM OF A CONTROLLED PROCESS

The management estimated that before the tank shoe contract was completed, the saving in tank shoes which could reasonably be attributed to the quality control effort was more than twenty times its cost.

QUALITY CONTROL PRINCIPLES

Experience in applying quality control, particularly in the chemical, metallurgical and process industries may be summed up in the following statements:

(a) Quality control provides its own yardstick.

(b) Make your process tell you.

(c) Don't neglect other tools.

(d) Make sure you have good data.

(e) Quality control of raw material and process variables leads to quality control of product.

(f) Quality control of variables at optimum levels leads to optimum product quality.

The last two statements may be illustrated diagrammatically by Figures 5 and 6. In Figure 5 arbitrary levels have been specified for raw material and process variables, none of which are controlled within limits. As a result the product is out of control and only part of it can be brought within the specified tolerance. In Figure 6 the variables are controlled about optimum levels, the product is in control, and there is no difficulty in keeping practically all the product within the specified tolerance.

SAMPLING INSPECTION

It was stated earlier that the two most widely used techniques in statistical quality control have been the control chart and the sampling inspection plan. The foregoing applications were based largely on the control chart. Space does not permit a similar discussion of sampling inspection. Although the control chart is primarily a test of a process, and sampling inspection is primarily a test of a product, much the same sort of reasoning is involved in both. In fact, when sampling inspection is applied right at or along the production line, and the information obtained is used to initiate corrective action when necessary, there is little difference between the two techniques.

When inspection is used at successive stages of a manufacturing operation and a controlled percentage of defective material can be tolerated, sampling inspection will provide a considerable saving over the 100 percent inspection often used in these circumstances.

A typical application of sampling inspection in a processing industry can be taken from the experience of the Dominion Rubber Company in which a quality control group has used training courses, sampling inspection, and control chart methods to improve efficiency of manufacture in the various plants of the company for several years.

In one operation in a plant producing rubber-soled footwear, 200 operators were engaged in making canvas uppers. A final 100 percent inspection was operating, although defectives could be caught in later operations at small expense. The time lag was too great to permit effective control. A sampling inspection (plus patrol) plan reduced defective workmanship about 65 percent in a few months' time, decreased repair items from five percent to one percent within a year, and reduced inspection costs in the department 25 percent. One feature of this application was a simplified control chart for percent defective which gave constant limits with varying sample size.

GENERAL APPLICABILITY OF QUALITY CONTROL

The foregoing discussion has been concerned largely with manufacturing, but it will be evident from the introductory remarks that quality control techniques have some application whenever it is necessary to deal with variable quantities. They are being used in Toronto at the present time for such diverse purposes as reducing the time required to handle claims for unemployment insurance and maintaining the efficiency of a fleet of trucks. Just as it has been shown that Quality Control leads the way to more efficient manufacturing, so it can be shown that it leads the way to more efficient Management, Sales, Engineering, Purchasing, Inspection, Chemical Analysis, Testing, and Research.

OTHER STATISTICAL METHODS

Although the quality control chart and sampling inspection plan offer the quickest returns for the effort expended in most industrial situations, nevertheless they constitute only two of a number of statistical techniques which may be applied with profit in particular circumstances.

Many quality engineers have learned to apply analysis of variance and correlation techniques in their work with good results. However, in complicated situations and, in particular, when planning elaborate surveys or experiments, the advice of experts in these fields should be sought.

In this connection, it may be of interest to note that the research organization with which the writer is associated established a department of mathematical statistics last year, and is finding this department of invaluable assistance in its work.

For those interested in advance techniques, it may be said that experience to date indicates that analysis of covariance is the most generally effective technique for dealing with research data. This technique frequently enables one to deal adequately with factors that enter an experiment in an arbitrary manner, provided that such factors can be measured.

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Quality Control in Post War Industry*

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It will be appropriate to begin the discussion of the subject by comparing some of the pertinent characteristics of our war-time activities with those which obtain under present conditions. For this discussion we shall select those characteristics which have had an important influence on quality control work and also which have been definitelly changed by the end of the war.

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COMPARISON OF WAR-TIME AND PRESENT CONDITIONS

A very large proportion of war-time production was concerned with new products. Tremendous amounts of war material comprised wholly new articles made for the first time during the war for very

special purposes. In addition although much of the material procured by government agencies during the war had, of course, been made previously, the requisite volume was so great that it was necessary to bring in personnel completely inexperienced in these types of manufacture. To all intents and purposes, these products were comparatively unknown to the operating personnel and hence could be classed as new products. This circumstance was decidedly beneficial to the introduction of quality control. Supervisory and operating personnel were placed under a heavy responsibility and had, in many cases, but little experience with which to meet that responsibility. Under these circumstances, they were willing to take up any new tool that promised assistance. It is quite certain that many of our vigorous war-time programs of quality control were initiated largely because of this reason.

This condition no longer exists. We are now concerned mainly with the manufacture of familiar items. The customary products of peace time are being produced, by and large, with the same methods that were used in the prewar period. Those of us who undertook a new and unfamiliar assignment during the war have, for the most part, returned to our previous occupations.

This return to familiar products and processes has raised a definite barrier to extension of quality control methods to those old-line products. Time and again, we meet the attitude, "What was good enough in prewar years, is good enough now. We made a good product before the war without these methods, why do we need them under present circumstances?" This does not imply that the need for quality control methods is lessened because of return to our familiar pursuits. Surely, all of us have recognized, however, that the accompanying return to our inherited prejudices has increased the difficulties of the quality engineer.

A further characteristic of war-time production lay in the fact that all industry worked for one customer, namely, the government. Numerous sales departments were to a large extent disbanded since the customer of those days dealt directly with production or inspection personnel. This unity of purchaser caused comparative uniformity in relations between user and producer. It is true, of course, that different agencies of the government sometimes gave the impression of being not only total strangers, but bitter enemies as well. These conditions were exceptional, however, and, as a general rule, the producing units worked for a single acceptance agency, whose representative was often located in the manufacturing unit. This situation simplified many of the customary relations between producer and consumer. Contact between production personnel and accepting personnel was closer and exchange of information more complete and rapid than is ordinarily the case. This circumstance was favorable to introduction of statistical acceptance methods and undoubtedly was responsible for much of the growth which took place along these lines.

Most manufacturing organizations have now reestablished their sales staffs and are selling to their usual many customers having a wide diversity of needs and greatly varying backgrounds. These variations may be so great that one product may be required to fulfill opposed requirements. The inevitable compromises cannot always be readily translated into the language of quality control. Production and inspection personnel no longer have the benefit of a government inspector who can rule on the seriousness of a defect. Instead, it is necessary to invoke experience and good guessing in the evaluation of acceptable quality levels. Further, the products themselves are loosely defined if, indeed, any definition is available.

The multiplicity of customers has a further effect on amplification of quality control methods. It is no longer possible for a whole industry to be converted to quality control acceptance methods by order of a single agency. This comparatively easy method of introducing quality control is obviously impractical when we are dealing with many customers, each possessing his own requirements. A further consequence is that when the initiative for establishing quality control is taken by the vendor, a much greater educational program is required because of the many sales contacts made by the average producing organization.

The final war-time characteristic that needs to be mentioned is the relatively subordinate position assumed by cost of production. Most of the war-time production program heavily emphasized quality. Indeed, at this remote distance, it is not unfair to say that quality was overglamorized. We can all remember the dire consequences predicted for comparatively minor defects. Presumably, such overemphasis is part of our way of doing things and need not be too greatly deplored. Regardless of the justification for this emphasis on quality, there is no question but that considerations of operating costs were less important in war-time than under more normal operating conditions.

It is hardly necessary to state that we have now returned to the condition where cost is the dominant factor in our manufacturing operations. Quality of product is assessed in terms of cost and success of quality control is assessed in terms of savings.

The quality engineer must ask for money to conduct his operations before he can demonstrate that savings are possible. After he has carried out his work and has contributed to the overall efficiency of his organization, it is not always easy for him to show just how great has been his contribution. Ordinarily, any major advance in operating efficiency is the result of activities by many groups. Each may justly claim his share, but the overall result is to make difficult the recognition of the actual savings which can be ascribed to the use of quality control.

EFFECTS OF POST WAR CONDITIONS ON QUALITY CONTROL WORK

These appear to be the principal contrasts between our war-time activities and those in which we are now engaged. Their effects on quality control work may be briefly summarized.

First, there seems to be going on a gradual shift in emphasis from acceptance control to process control. This is all to the good, since it is here that quality control methods can effect the greatest savings.

In this connection, it seems desirable to define just what we mean by a satisfactory quality control program. Such a program involves much more than merely maintaining control charts on important quality characteristics. In order that the program be complete, each chart must be made the basis of action. This action must be taken with sufficient promptness to accomplish the desired result. The indicated action must be both of a short-range nature to remedy existing troubles, and also of a long-range type to prevent the recurrence of these troubles. This involves close cooperation of production, engineering, and development departments. Only with this type of cooperation and aggressive action can we consider the quality control program to be reasonably complete.

Next, we may consider the effect of emphasis on cost. As a result of this, the quality engineer must exercise skillful salesmanship in the conduct of his activities. Unless he can enlist the inter-departmental cooperation indicated above, he will find it impossible to maintain his program in a healthy state of expansion. Successful salesmanship of this type is not always easy to develop. It frequently seems unreasonable that other departments in a manufacturing operation are so slow to recognize the manifest advantages of statistical control.

This reactionary point of view is easier to understand if we remember that we, as professional men, have a different outlook from that of the production man or the executive. We start out with faith in the method which we propose to apply. As a result, we are ready to give a favorable interpretation to any savings which may be effected. Indeed, we are so sure of success that we hardly think it necessary to investigate these savings in any detail. It is hard for us to realize that the nonprofessional man takes quite a different attitude.

For the most part, he does not understand the basic principles which we apply. Furthermore, we are telling him that, in spite of his years of experience, we know more about running his job than he does, or at least about certain aspects of his job. These things breed suspicion. Unless we recognize the point of view of a nonprofessional man and work to overcome it, we will have great difficulty in functioning effectively.

This does not mean that we should attempt to teach every member of the plant elementary statistics. Quite the contrary. It does mean that we should cultivate the sympathy and cooperation of the men with whom we work, and that we must lean over backwards in giving them full credit for their share in any accomplishment to which our statistical methods may have contributed.

The principal characteristic of postwar operation, however, is that introduction of quality control work and amplification of these activities have become increasingly difficult. Each of the characteristics discussed above has had the result of making things harder for the quality engineer. We can say that, just as in the case with our international relations, we are finding it more difficult to wage the peace than it was to fight the war.

The increased difficulty of quality control work should be considered a challenge rather than a discouragement. If this type of work has become more difficult, it will become more rewarding. The incentives of success are even greater than they were during the war, since they may fairly be considered to include permanent contributions to the national welfare and definite increases in standard of living due to more efficient use of the men, machines, and materials with which we work.

THE FUTURE FOR QUALITY CONTROL

It is difficult to avoid some speculation concerning the future for quality control. We have seen these methods applied mainly to inspection and the assurance of quality. Shewhart, however, has envisioned a much wider application of his methods, so that in the perfect industry they should be applied to every phase of the operation, from procurement of raw materials to sales of the finished product.

Should we not look forward to the next phase of our activities to which these methods may be applied? One of the most promising of the new fields to conquer should be that comprising purchasing and sales. It is not too much to look forward to the day when practically all of the goods sold in this country are offered for sale with the assurance that they have been produced under a system of standard quality control methods. Such assurance should be much more satisfactory than that given by any self-styled institute operated by a family publication or other private institution. Serious thought should be given to indoctrinating our purchasing departments and sales staffs wherever possible in the advantages that they may obtain by purchasing and selling by means of a control chart.

In this connection, it might be interesting to obtain an index of the extent to which industry has adopted quality control methods. It is doubtful whether such an index could be obtained from a study of process control by means of control charts. The influence played by control charts in different industries and in different units of the same industry differs so greatly that comparison seems impossible. However, it should be possible to sample purchasing agents and ask them whether they buy goods on the basis of control charts offered by the vendor or by their own accepting departments. Similarly, it should be possible to sample sales divisions and to ask whether they sell their products by means of a control chart. From certain advertisements that have appeared in technical publications within the last year or so, it seems likely that some positive answers would be obtained, but undoubtedly the actual volume of goods exchanged on this basis is extremely small.

In conclusion, we may adopt an optimistic point of view, in spite of the difficulties that have been enumerated. There is a tremendous task to be done. The very magnitude of this task assures ample opportunity for the members of this new profession. All that we have seen during the war and since, indicates the desirability of extending quality control to new fields. No doubt, there will be discouragements, but we can definitely look forward to major accomplishments in the coming years.

Analysis of Variance*

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Part II – ANALYSIS OF A TWO-WAY LAYOUT FOR ROW, COLUMN, AND INTERACTION EFFECTS

INTRODUCTION

In Part I it was shown how a two-way layout in which individual values were arranged in columns and rows could be analyzed for column effects and row effects. If we consider our table as divided into columns, rows, and "cells" as illustrated below, then there was one individual observed value in each cell of the table analyzed.

			Column	
Row			Cell	

In this part we shall consider the case in which we have more than one individual observed value in each cell of the table, the second, third, fourth, etc. value in each cell having been obtained under essentially the same conditions as the first in an effort to duplicate it. With this extra information we can carry the analysis further. In addition to testing for row and column effects, we can also test for what are called "interaction" effects.

INTERACTION EFFECTS

A pure interaction effect is such that a fixed amount is added to or subtracted from all the observations in a cell, the amount varying from cell to cell in such a way that the net effect on any row or column total is zero.

*Editorial Note: Part I of this paper appeared in the March, 1948, issue of IQC. Parts II and III in this issue complete the paper.

In terms of differences between means as discussed in Part I, an interaction thus consists of differences between the means of the sub-lots corresponding to the cells, which are over and above any differences in the means of the sub-lots corresponding to columns and rows.

Let us suppose that we have four methods of analyzing for copper content and that we wish to try them out on a standard material using three analysts. We can then picture a table of data such as that illustrated below in which the columns correspond to the analytical methods and the rows to analysts.

		Analytical Method			
		A	B	C	D
Analyst	(i)			X	
	(ii)				
	(iii)				

We would enter the analytical values obtained by analyst (i) using method C in the cell in the first row and third column as indicated by the X in the diagram, and so on throughout the table. If the analytical methods differed in the percentage of copper they would recover that would introduce column effects; if the analysts differed in their ability to avoid losses in the analyses that would introduce row effects; if, **in addition**, the analysts reacted differently to the different methods, that would introduce interaction effects.

SYNTHETIC EXAMPLE – NO RANDOM ERROR

In order to illustrate what we mean by these various effects in this kind of analysis of variance, it is instructive to build up a synthetic case and then analyze it.

Let us suppose that the standard material actually should give a value of 50 percent copper; i.e. if analyzed repeatedly by the three analysts using the four methods and averaging, a value of 50 percent would be obtained. The true copper content might not be exactly 50 percent, but this kind of experiment would not decide such a question. If none of the effects mentioned and no random errors were present, we would obtain a table of data such as Table I. Repetition would give us more values in each cell but all the values would equal 50.

TABLE I

Analysts	Method			
	A	B	C	D
(i)	50	50	50	50
(ii)	50	50	50	50
(iii)	50	50	50	50

Now, we may, by way of example, introduce column effects by adding the values in Table II, row effects by adding those in Table III and interaction effects by adding those in Table IV, in each case adding them to the corresponding cells in Table I.

If we examine Tables II, III and IV, we see that II will affect only the column totals or means, III only the row totals or means, and IV will not effect either the row or column totals or means.

TABLE II
EXAMPLE OF COLUMN EFFECTS

Analysts	Method			
	A	B	C	D
(i)	−1	0	0	+1
(ii)	−1	0	0	+1
(iii)	−1	0	0	+1

TABLE III
EXAMPLE OF ROW EFFECTS

Analysts	Method			
	A	B	C	D
(i)	1	1	1	1
(ii)	0	0	0	0
(iii)	−1	−1	−1	−1

TABLE IV
EXAMPLE OF INTERACTION EFFECTS

Analysts	Method			
	A	B	C	D
(i)	0	0	0	0
(ii)	−2	1	0	1
(iii)	+2	−1	0	−1

If we add up these four tables, we obtain Table V in which there will be column, row, and interaction effects but, so far, no random variation. However, one would have difficulty in spotting these effects by just looking at this table.

TABLE V
EXAMPLE WITH ROW, COLUMN, AND INTERACTION EFFECTS BUT NO RANDOM ERROR

Analysts	Method			
	A	B	C	D
(i)	50	51	51	52
(ii)	47	51	50	52
(iii)	50	48	49	49

We have not yet considered any random error; in other words, if we duplicated Table V with the same methods, analysts, and materials, we would get exactly the same table of values again under our assumption so far. It is still possible to unscramble the effects. Thus, if we find the means of the columns, rows, and overall mean as shown in Table VI, and then subtract the overall mean (50), we get Table VII in which our row and column effects are shown by the means to the right and bottom respectively.

TABLE VI
TABLE V WITH MEANS SHOWN (NO ERROR PRESENT)

Analysts	Method				Mean
	A	B	C	D	
(i)	50	51	51	52	51
(ii)	47	51	50	52	50
(iii)	50	48	49	49	49
Mean	49	50	50	51	50

TABLE VII
GENERAL MEAN SUBTRACTED FROM TABLE VI

Analysts	Method				Mean
	A	B	C	D	
(i)	0	1	1	2	1
(ii)	−3	1	0	2	0
(iii)	0	−2	−1	−1	−1
Mean	−1	0	0	1	0

By subtracting the row and column means in Table VII we then get Table VIII in which we are back to Table IV and have recovered our interactions.

TABLE VIII
INTERACTIONS RECOVERED
(COMPARE WITH TABLE IV)

Analysts	Method			
	A	B	C	D
(i)	0	0	0	0
(ii)	−2	1	0	1
(iii)	+2	−1	0	−1

RANDOM ERROR

We have seen that in the absence of any random error, we can build up a table containing column, row, and interaction effects and readily get them back again in exactly the same form as they were introduced.

In actual practice we have to contend with situations in which random error is also present. This may come from one **or all** of many sources. In the example we have been discussing it might be due to variation in the standard material analyzed, to errors in weighing, to limitations of the equipment used, to unconscious variation in the techniques of the analysts, to difficulty in determining end points in titration, to changes in laboratory conditions if all analyses could not be done on one day, etc. All of these factors influencing the final result are lumped together and called "error" in this kind of calculation. In addition, it is assumed that the deviations caused in the final result are random deviations distributed according to the normal law with mean zero and the same standard deviation for every cell in the table. With these assumptions, and by providing an equal number of values in each cell of the table, the calculations are greatly simplified.

In order to complete our synthetic example we can introduce random error by using a bowl of Bingo chips numbered from − 5 to +5 with frequencies such as to simulate a normal distribution having mean zero and standard deviation 1.715. (See Appendix A).

ADDITION OF RANDOM ERROR

Let us return now to Table V which had column, row, and interaction effects but no random error. If we repeated this experiment five times with the same material, methods, and analysts but still in the absence of any error, we would get a table like Table IX. Now, if we set up a similar table, Table X, we can fill it up by drawing Bingo chips at random from the bowl to give us a random error for each value in Table IX. (The errors shown are those drawn in one of the evening classes in Quality Control at the University of Toronto).

By adding the corresponding numbers in Tables IX and X together we obtain Table XI in which we at last have column effects, row effects, interaction effects, and random error.

This is the form in which the data are actually obtained in an experiment of this kind, but for the purpose of analysis we consider it as having been built up exactly as we have built up our synthetic example. That is, we consider each value in the table as being obtained by starting with a general mean value and adding to it possible column effect, row effect, interaction effect, and random error.

In fact, it is like an assembly line in which each order (determination) starts out with a designation showing the cell in which it will finally be located, say C, (iii). In turn, there is added to it the theoretical general mean 50, the C column effect (0), the (iii) row effect (−1), the C, (iii) interaction effect (0), and an error drawn at random from a normal population with mean zero.

TABLE IX
REPETITION WITHOUT ERROR

Analysts	Method			
	A	B	C	D
(i)	50	51	51	52
	50	51	51	52
	50	51	51	52
	50	51	51	52
	50	51	51	52
(ii)	47	51	50	52
	47	51	50	52
	47	51	50	52
	47	51	50	52
	47	51	50	52
(iii)	50	48	49	49
	50	48	49	49
	50	48	49	49
	50	48	49	49
	50	48	49	49

TABLE X
RANDOM ERRORS ONLY

Analysts	Method			
	A	B	C	D
(i)	3	−1	1	−2
	−2	2	−1	0
	−5	0	−1	−2
	0	2	−3	2
	−1	0	0	2
(ii)	2	0	−2	2
	−3	−1	1	1
	1	1	2	1
	−1	2	−1	−1
	0	1	0	0
(iii)	1	0	0	−2
	−1	0	2	0
	−2	−2	−2	3
	−2	3	3	−2
	1	2	0	−2

TABLE XI
EXAMPLE CONTAINING COLUMN EFFECTS, ROW EFFECTS, INTERACTION EFFECTS, AND RANDOM ERROR

Analysts	Method			
	A	B	C	D
(i)	53	50	52	50
	48	53	50	52
	45	51	50	50
	50	53	48	54
	49	51	51	54
(ii)	49	51	48	54
	44	50	51	53
	48	52	52	53
	46	53	49	51
	47	52	50	52
(iii)	51	48	49	47
	49	48	51	49
	48	46	47	52
	48	51	52	47
	51	50	49	47

OBJECT OF ANALYSIS OF VARIANCE

We have seen that Table VI or Table IX in which no random error is present can be taken apart readily to show the various effects. However, Table XI presents more difficulty because we have added a random error to each value. If we continued the experiment, piling up more and more values in each cell and averaging, we would eventually get back to Table VI because the random errors have a mean of zero and would tend to cancel out. This would be an expensive way to find if column, row, or interaction effects are present. We want to do the best we can using the five values in each cell shown in Table XI. That is the object of the analysis of variance.

ANALYSIS OF VARIANCE

If we carry through the analysis of variance of Table XI as shown in Appendix B, we end up with the Analysis of Variance Table XII, which is similar to that obtained in Part I but now has an interaction and error term.

With 60 observations in Table XI, the total degrees of freedom is 59. The interaction degrees of freedom is the product of those of the columns and rows, leaving 48 for error.

The F values in the fourth column are obtained by dividing the mean squares in the third column by the error mean square because we want to know if they can be explained by the random error. These F values are much higher than the $F_{.05}$ values obtained from the F tables, so we conclude that significant column, row, and interaction effects are present, since we would expect values as large as the F values in the fourth column less than once in twenty times otherwise.

TABLE XII
ANALYSIS OF VARIANCE OF TABLE XI

	Degrees of Freedom	Sum of Squares	Mean Square	F	$F_{.05}$
Columns (Methods)	3	58.850	19.617	5.88	2.8
Rows (Analysts)	2	31.033	15.516	4.65	3.2
Interaction (R x C)	6	71.100	11.850	3.56	2.3
Error	48	160.000	3.333		
Total	59	320.983			

TABLE XIII
ANALYSIS OF VARIANCE OF TABLE X
(RANDOM ERROR ONLY)

	Degrees of Freedom	Sum of Squares	Mean Square	F	$F_{.05}$
Columns	3	10.850	3.617	1.08	2.8
Rows	2	3.033	1.516	(2.20)*	19.5
Interactions	6	7.100	1.183	(2.82)	3.8
Error	48	160.000	3.333		
Total	59	180.983	3.068		

*The bracketed values are reciprocals of F as ordinarily computed. The same table of $F_{.05}$ can be used provided n_1 is always associated with the larger mean square. As pointed out in Section 3, Part I, a significant value on this basis provides a reason for questioning the value of the data or the method of analysis and destroys the basis of the more usual F test.

Thus, we have been able to show that column, row, and interaction effects are present in spite of the obscuring effect of random error.

ANALYSIS OF RANDOM ERROR

It is instructive to repeat the above analysis using Table X in which only random error is present. This is done in Appendix C. The result is shown in Table XIII.

The values of F in the fourth column are now all lower than $F_{.05}$ values from the tables of F so that no significant column, row, or interaction effects are indicated, which we know to be a correct conclusion.

The mean square calculated from the total sums of squares is 3.068 and in the known absence of the other effects may be taken as an estimate of the variance of the Bingo chip population. We know that this was $(1.715)^2 = 2.941$.

Knowing that the variance of random error was 2.941, we can set up Table XIV, which gives the theoretical counterpart of Table XIII.

A WORD OF CAUTION

We have demonstrated the meaning of column effects, row effects, interaction effects, and random error and the method to be used in deciding if these effects are significant. We have limited the discussion to one kind of experiment, i.e. one in which repetition involves duplicating the values in the cells with fixed column, row, and interaction effects unchanged throughout the experiment. This is the case most commonly met in practice and the best to learn first. However, analysis of variance can be applied in a number of other kinds of situation, and it should not be assumed that every two-way table can be analyzed and interpreted as shown above.

Also, in the above analysis, it was assumed that all random errors came from the same population. This assumption can be checked by running an R or σ control chart using the groups of values in the cells as sub-groups or by using Bartlett's test.*

IMPORTANCE OF INTERACTIONS

The ability to detect interactions is useful in industrial control, in testing and analysis, and in research work.

In industrial control, interactions may be responsible for variations in a process or product which would be difficult to eliminate if we did not know their nature. In testing and analysis, test methods or analytical methods that are free from

*Test for heterogeneity of variance. M. G. Kendall, "The Advanced Theory of Statistics," Vol. II, p.299; C. Griffin & Co., Ltd., 1948.

TABLE XIV
THEORETICAL ANALYSES OF VARIANCE OF RANDOM ERROR ONLY

	Degrees of Freedom	Sum of Squares	Mean Squares	F
Columns	3	8.823	2.941	1
Rows	2	5.882	2.941	1
Interactions	6	17.646	2.941	1
Error	48	141.168	2.941	
Total	59	173.519		

interactions with analysts, test machines, etc. are much to be preferred. It is usually possible to correct for row and column effects but difficult to correct for interactions. Experience shows too that the presence of interactions usually indicates a fundamental weakness in the method.

In experimental work, the absence of interactions may justify us in making more general conclusions. Let us suppose we are testing several fabrics by means of consumer wear tests. We may arrange matters so our rows correspond to the fabrics tested and the columns to different occupations of the wearers. If we choose widely different occupations and still get no column-row interactions we feel justified in assuming that our fabric comparisons will hold over a wide range of occupations.

APPENDIX A

FREQUENCY DISTRIBUTION OF NUMBERS ON BINGO CHIPS

Numbers	−5	−4	−3	−2	−1	0	1	2	3	4	5	Total	Mean	σ'	$(\sigma')^2$
Frequency	1	3	10	23	39	48	39	23	10	3	1	200	0	1.715	2.941

APPENDIX B

TABLE XV—CODED VALUES—ANALYSIS OF VARIANCE OF TABLE XI
(Values of Table XI, Part II, Coded by Subtracting 50)

Analysts	Methods A		Methods B		Methods C		Methods D		R	R^2
(i)	3	(9)	0	(0)	2	(4)	0	(0)	14	196
	−2	(4)	3	(9)	0	(0)	2	(4)		
	−5	(25)	1	(1)	0	(0)	0	(0)		
	0	(0)	3	(9)	−2	(4)	4	(16)		
	−1	(1)	1	(1)	1	(1)	4	(16)		
(ii)	−1	(1)	1	(1)	−2	(4)	4	(16)	5	25
	−6	(36)	0	(0)	1	(1)	3	(9)		
	−2	(4)	2	(4)	2	(4)	3	(9)		
	−4	(16)	3	(9)	−1	(1)	1	(1)		
	−3	(9)	2	(4)	0	(0)	2	(4)		
(iii)	1	(1)	−2	(4)	−1	(1)	−3	(9)	−20	400
	−1	(1)	−2	(4)	1	(1)	−1	(1)		
	−2	(4)	−4	(16)	−3	(9)	2	(4)		
	−2	(4)	1	(1)	2	(4)	−3	(9)		
	1	(1)	0	(0)	−1	(1)	−3	(9)		
C	−24	(116)	9	(63)	−1	(35)	15	(107)	−1	621
C^2	576		81		1		225		883	(321)*

*The bracketed numbers are used in arriving at the sum of squares of the tabulated values.

TABLE XVI—CELL TOTALS (E) FROM TABLE XV

Analysts	Methods A		Methods B		Methods C		Methods D		R	
(i)	−5	(25)	8	(64)	1	(1)	10	(100)	14	
(ii)	−16	(256)	8	(64)	0	(0)	13	(169)	5	
(iii)	−3	(9)	−7	(49)	−2	(4)	−8	(64)	−20	
C	−24	(290)	9	(177)	−1	(5)	15	(333)	−1	(805)*

*The bracketed numbers are used in arriving at the sum of squares of the tabulated values. The C and R values are a check on Table XV.

$Q_1 = \Sigma X^2 / 1 = 321$
$Q_2 = \Sigma E^2 / 5 = 805 / 5 = 161$
$Q_3 = \Sigma C^2 / 15 = 883 / 15 = 58.867$
$Q_4 = \Sigma R^2 / 20 = 621 / 20 = 31.05$
$Q_5 = T^2 / 60 = 1 / 60 = 0.017$

(X = Individual Value)
(E = Cell Total)
(C = Column Total)
(R = Row Total)
(T = Grand Total)

Total	Cells	Methods	Analysts
$Q_1 = 321.000$	$Q_2 = 161.000$	$Q_3 = 58.867$	$Q_4 = 31.050$
$Q_5 = 0.017$	$Q_5 = 0.017$	$Q_5 = 0.017$	$Q_5 = 0.017$
320.983	160.983	58.850	31.033

$$\text{Error} = (Q_1 - Q_5) - (Q_2 - Q_5) = 320.983 - 160.983 = 160.000$$

$$\text{Method and Analyst Interaction} = (Q_2 - Q_5) - (Q_3 - Q_5) - (Q_4 - Q_5)$$
$$= 160.983 - (58.850 + 31.033)$$
$$= 71.100$$

Note. The general computational procedure is the same as shown in Part I. Q_2 is new and is the sum of squares of the cell totals divided by the number of individual values in a cell. The divisor in each case is the number of individual values added together to get **one** of the numbers squared and summed in the numerator.

TABLE XVII—ANALYSIS OF VARIANCE TABLE—APPENDIX B

	Sums of Squares	Degrees of Freedom	Mean Squares	F	$F_{.05}$
Methods	58.850	3	19.617	5.89	2.8
Analysts	31.033	2	15.616	4.69	3.2
Method & Analyst Interaction	71.100	6	11.850	3.56	2.3
Error	160.000	48	3.333		
Total	320.983	59			

APPENDIX C

TABLE XVIII—ANALYSIS OF VARIANCE OF TABLE X
This follows exactly the same pattern as Appendix B
(Values of Table X, Part II)

Analysts	Methods A		Methods B		Methods C		Methods D		R	R^2
(i)	3	(9)	−1	(1)	1	(1)	−2	(4)	−6	36
	−2	(4)	2	(4)	−1	(1)	0	(0)		
	−5	(25)	0	(0)	−1	(1)	−2	(4)		
	0	(0)	2	(4)	−3	(9)	2	(4)		
	−1	(1)	0	(0)	0	(0)	2	(4)		
(ii)	2	(4)	0	(0)	−2	(4)	2	(4)	5	25
	−3	(9)	−1	(1)	1	(1)	1	(1)		
	1	(1)	1	(1)	2	(4)	1	(1)		
	−1	(1)	2	(4)	−1	(1)	−1	(1)		
	0	(0)	1	(1)	0	(0)	0	(0)		
(iii)	1	(1)	0	(0)	0	(0)	−2	(4)	0	0
	−1	(1)	0	(0)	2	(4)	0	(0)		
	−2	(4)	−2	(4)	−2	(4)	3	(9)		
	−2	(4)	3	(9)	3	(9)	−2	(4)		
	1	(1)	2	(4)	0	(0)	−2	(4)		
C	−9	(65)	9	(33)	−1	(39)	0	(44)	−1	61
C^2	81		81		1		0		163	(181)*

*The bracketed numbers are used in arriving at the sum of the squares of the tabulated values.

TABLE XIX—CELL TOTALS FROM TABLE VIII

Analysts	Methods								R	
	A		B		C		D			
(i)	−5	(25)	3	(9)	−4	(16)	0	(0)	−6	
(ii)	−1	(1)	3	(9)	0	(0)	3	(9)	5	
(iii)	−3	(9)	3	(9)	3	(9)	−3	(9)	0	
C	−9	(35)	9	(27)	−1	(25)	0	(18)	−1	(105)*

*The bracketed numbers are used in arriving at the sum of squares of the tabulated values. The C and R values are a check on Table XVIII.

$Q_1 = \Sigma X^2/1 = 181$
$Q_2 = \Sigma E^2/5 = 105/5 = 21$
$Q_3 = \Sigma C^2/15 = 163/15 = 10.867$
$Q_4 = \Sigma R^2/20 = 61/20 = 3.05$
$Q_5 = T^2/60 = 1/60 = 0.017$

(X = Individual Value)
(E = Cell Total)
(C = Column Total)
(R = Row Total)
(T = Grand Total)

Total	Cells	Methods	Analysts
$Q_1 = 181.000$	$Q_2 = 21.000$	$Q_3 = 10.867$	$Q_4 = 3.050$
$Q_5 = 0.017$	$Q_5 = 0.017$	$Q_5 = 0.017$	$Q_5 = 0.017$
180.983	20.983	10.850	3.033

Error $= (Q_1 - Q_5) - (Q_2 - Q_5) = 180.983 - 20.983 = 160$

Method and Analyst Interaction $= (Q_2 - Q_5) - (Q_3 - Q_5) - (Q_4 - Q_5)$
$= 20.983 - (10.850 + 3.033) = 7.100$

TABLE XX—ANALYSIS OF VARIANCE TABLE—APPENDIX C

	Sums of Squares	Degrees of Freedom	Mean Squares	F	$F_{.05}$
Methods	10.850	3	3.616	1.085	2.8
Analysts	3.033	2	1.516	(2.195)*	19.5
Method & Analyst Interaction	7.100	6	1.183	(2.817)	3.8
Error	160.000	48	3.333		
Total	180.983	59	3.068		

*The bracketed values are reciprocals of F as ordinarily computed. The same table of $F_{.05}$ can be used provided n_1 is always associated with the larger mean square. See footnote Table XIII for discussion.

PART III – PRACTICAL EXAMPLES

EXAMPLE A—TEST FOR COLUMN EFFECT

Ball bearing races are checked for ovalness on a gauge which automatically records the extent of the out-of-round condition. The gauge is part of a line inspection system, and it is suspected that some examiners are more adept in

TABLE I—RECORD OF GAUGING TIMES (Seconds)

Examiner				
1	2	3	4	5
13	14	14	15	13
14	14	15	14	16
12	13	13	14	14
14	14	15	14	14

its use than others. Each of the examiners is timed on four different occasions and the gauging time recorded as shown in Table I.

Do the examiners differ significantly in their gauging speed?

The values are coded by subtracting 10 and then analyzed as shown in Tables II and III.

TABLE II—CODED GAUGING TIMES

	Examiner 1		2		3		4		5		Totals	
	X	X^2	X	X^2	X	X^2	X	X^2	X	X^2		
	3	(9)	4	(16)	4	(16)	5	(25)	3	(9)		
	4	(16)	4	(16)	5	(25)	4	(16)	6	(36)		
	2	(4)	3	(9)	3	(9)	4	(16)	4	(16)		
	4	(16)	4	(16)	5	(25)	4	(16)	5	(25)		
C	13	(45)	15	(57)	17	(75)	17	(73)	18	(86)	80	(336)
C^2	169		225		289		289		324		1296	

$Q_1 = \Sigma X^2/1 = 336$ (X = Individual Value)
$Q_3 = \Sigma C^2/4 = 1296/4 = 324$ (C = Column Total)
$Q_5 = T^2/20 = 80^2/20 = 6400/20 = 320$ (T = Grand Total)

TABLE III—ANALYSIS OF VARIANCE TABLE—EXAMPLE A

	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$
Columns	$Q_3 - Q_5 = 4$	4	1.00	1.25	3.06
Residual	$Q_1 - Q_3 = 12$	15	0.80		
Total	$Q_1 - Q_5 = 16$	19			

Although F is greater than one, it is less than $F_{.05}$, and it is concluded that the data do not show a significant difference between examiners.

EXAMPLE B—TEST FOR COLUMN AND ROW EFFECT

A 24-hour cumulative sample of city gas is collected from a main and tested for calorific value each day from Monday to Saturday inclusive for nine weeks. The coded values of each test are shown in Table IV. In this case there is the possibility of a significant row effect because the day of the week to a large extent determines the amount and nature of the gas demand to be met and other conditions that affect operations. In addition, there may be a change from week to week in the quality of the coal and other factors.

Since there is only one value in each cell of the table, the analysis will not distinguish between interaction effects and within-cell variation as is done in example C which follows. In order to make the analysis, it is necessary to assume that interaction is absent. If this is not the case, the test for row and column effects will be less sensitive. While nominally on an $F_{.05}$ level of significance, it will actually be on a much more conservative level such as $F_{.01}$, and will also lead to very low values of F more frequently than would otherwise be the case.

TABLE IV—CODED CALORIFIC VALUE

Day	Week Number 1	2	3	4	5	6	7	8	9	R	R^2
Mon.	5	1	−4	5	−13	−8	−2	−4	−10	−30	900
Tues.	3	6	−10	−2	−7	−2	−4	2	2	−12	144
Wed.	8	4	−14	−3	3	0	5	−11	−12	−20	400
Thur.	8	10	−5	−1	4	−2	4	1	−12	7	49
Fri.	4	−1	7	−5	5	−3	−7	−3	−6	−9	81
Sat.	3	−9	3	−8	−6	0	−3	8	−1	−13	169
C	31	11	−23	−14	−14	−15	−7	−7	−39	−77	1743
C^2	961	121	529	196	196	225	49	49	1521	3847	

$Q_1 = \Sigma X^2/1 = 2093$ (X = Individual Value)
$Q_3 = \Sigma C^2/6 = 3847/6 = 641.17$ (C = Column Total)
$Q_4 = \Sigma R^2/9 = 1743/9 = 193.67$ (R = Row Total)
$Q_5 = T^2/54 = (-77)^2/54 = 5929/54 = 109.80$ (T = Grand Total)

TABLE V—ANALYSIS OF VARIANCE TABLE—EXAMPLE B

	Sum of Squares		Degrees of Freedom	Mean Squares	F	$F_{.05}$
Columns (weeks)	(Q_3-Q_5)	531.37	8	66.42	1.94	2.2
Rows (days)	(Q_4-Q_5)	83.87	5	16.77	(2.04)	4.5
Residual	$(Q_1-Q_3-Q_4+Q_5)$	1367.96	40	34.20		
Total	(Q_1-Q_5)	1983.20	53			

Although the value of F for columns is greater than one it is less than $F_{.05}$ and consequently not significant at the .05 level. The value of F for rows is less than one. We conclude, therefore, that there is no week or day effect in the data. The reciprocal of F for rows, shown in brackets, is also less than the corresponding $F_{.05}$ and therefore provides no reason for doubting the data or method of analysis.

EXAMPLE C—TEST FOR COLUMN, ROW, AND COLUMN— ROW INTERACTION EFFECTS

Five batches of ground meat are charged consecutively to a rotary filling machine for packing into cans. The machine has six filling cylinders. Three filled cans are taken from each cylinder at random while each batch is being run. The weights of the cans, coded by subtracting 12 oz., are shown in Table VI. The data are to be examined for significant batch to batch differences, cylinder to cylinder differences, or batch-cylinder interaction.

Differences in batches might occur from changes in fat-lean ratio, air content, moisture content, etc., since the machine works essentially on a volumetric basis. Differences between cylinders are likely to be mechanical in nature, mainly lack of standardization in piston stroke. Thus a significant batch effect would indicate the need for closer control of meat density; a significant cylinder effect would show the need for mechanical adjustment.

An interaction would most likely indicate a change with time of the realtive adjustment of the pistons, or possibly a difference in their reaction to batches of different consistency.

The residual, or error term, would reflect weighing errors, variation in (empty) can weights, within-batch variation in the meat, play in the machine, etc.

TABLE VI—CODED WEIGHTS OF FILLED CANS

Cylinder	Batch 1		Batch 2		Batch 3		Batch 4		Batch 5		R	R^2
1	1	(1)	4	(16)	6	(36)	3	(9)	1	(1)	46	2116
	1	(1)	3	(9)	3	(9)	1	(1)	3	(9)		
	2	(4)	5	(25)	7	(49)	3	(9)	3	(9)		
2	−1	(1)	−2	(4)	3	(9)	2	(4)	1	(1)	14	196
	3	(9)	1	(1)	1	(1)	0	(0)	0	(0)		
	−1	(1)	0	(0)	5	(25)	1	(1)	1	(1)		
3	1	(1)	2	(4)	2	(4)	1	(1)	3	(9)	31	961
	1	(1)	0	(0)	4	(16)	3	(9)	3	(9)		
	1	(1)	1	(1)	3	(9)	3	(9)	3	(9)		
4	−2	(4)	−2	(4)	3	(9)	0	(0)	0	(0)	14	196
	3	(9)	0	(0)	3	(9)	0	(0)	1	(1)		
	0	(0)	1	(1)	4	(16)	2	(4)	1	(1)		
5	1	(1)	2	(4)	0	(0)	1	(1)	−2	(4)	14	196
	1	(1)	1	(1)	1	(1)	0	(0)	3	(9)		
	−1	(1)	5	(25)	2	(4)	−1	(1)	1	(1)		
6	0	(0)	0	(0)	3	(9)	3	(9)	3	(9)	26	676
	1	(1)	0	(0)	3	(9)	0	(0)	1	(1)		
	1	(1)	3	(9)	4	(16)	2	(4)	2	(4)		
C	12	(38)	24	(104)	57	(231)	24	(62)	28	(78)	145	4341
C^2	144		576		3249		576		784		5329	(513)*

*The bracketed numbers are used in arriving at the sum of squares of the tabulated values.

TABLE VII—CELL TOTALS—EXAMPLE C

Cylinder	Batch 1		2		3		4		5		R
1	4	(16)	12	(144)	16	(256)	7	(49)	7	(49)	46
2	1	(1)	−1	(1)	9	(81)	3	(9)	2	(4)	14
3	3	(9)	3	(9)	9	(81)	7	(49)	9	(81)	31
4	1	(1)	−1	(1)	10	(100)	2	(4)	2	(4)	14
5	1	(1)	8	(64)	3	(9)	0	(0)	2	(4)	14
6	2	(4)	3	(9)	10	(100)	5	(25)	6	(36)	26
C	12	(32)	24	(228)	57	(627)	24	(136)	28	(178)	145 (1201)*

*The bracketed numbers are used in arriving at the sum of squares of the tabulated values. The C and R values are a check on Table VI.

$Q_1 = \Sigma X^2/1 = 513/1 = 513$ (X = Individual Value)
$Q_2 = \Sigma E^2/3 = 1201/3 = 400.33$ (E = Cell Total)
$Q_3 = \Sigma C^2/18 = 5329/18 = 296.06$ (C = Column Total)
$Q_4 = \Sigma R^2/15 = 4341/15 = 289.40$ (R = Row Total)
$Q_5 = T^2/90 = 145^2/90 = 21025/90 = 233.61$ (T = Grand Total)

Total	Cells	Batches	Cylinders
$Q_1 = 513.00$	$Q_2 = 400.33$	$Q_3 = 296.06$	$Q_4 = 289.40$
$Q_5 = 233.61$	$Q_5 = 233.61$	$Q_5 = 233.61$	$Q_5 = 233.61$
279.39	166.72	62.45	55.79

Error $= (Q_1 - Q_5) - (Q_2 - Q_5) = 279.39 - 166.72 = 112.67$

Batch and Cylinder Interaction $= (Q_2 - Q_5) - (Q_3 - Q_5) - (Q_4 - Q_5)$
$= 166.72 - (62.45 + 55.79) = 48.48$

TABLE VIII—ANALYSIS OF VARIANCE TABLE—EXAMPLE C

	Sum of Squares	Degrees of Freedom	Mean Squares	F	$F_{.05}$
Batches	62.44	4	15.61	8.30	2.52
Cylinders	55.78	5	11.16	5.94	2.37
Batch & Cylinder Iteraction	48.48	20	2.42	1.29	1.75
Error	112.67	60	1.88		
Total	279.39	89			

In this case all the values of F are greater than one, but only those for batches and cylinders are greater than $F_{.05}$ values. Thus, the data indicate a large batch and cylinder effect but not a significant interaction. Adjustment of the piston strokes and closer control of meat density is indicated.

CONFERENCE PAPERS

29 of the Papers Given at the Second Annual Midwest Quality Control Conference, June, 1947

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Syracuse Section—Problem Clinic No. 2

GEORGE A. HUNT

BRISTOL LABORATORIES INCORPORATED

The second "What's Your Problem" program of the Syracuse Section of ASQC followed the pattern of the (member training—plant clinic) meeting described in the January, 1948 issue of this magazine, pages 25-27.

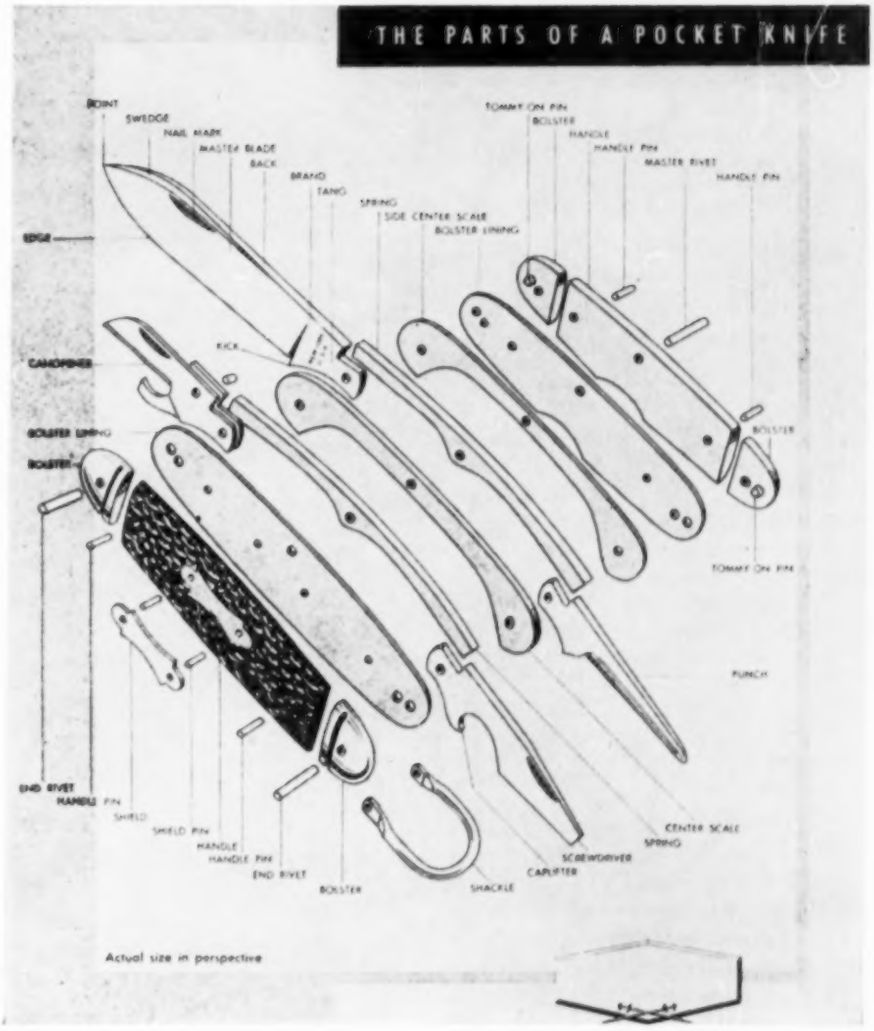
The following prospectus was prepared by the Syracuse Section Program Committee and the staff of a Cutlery Company, and was mailed to members together with the announcement of the meeting so as to be in members' hands ten days before the meeting.

"WHAT'S YOUR PROBLEM?"

A local cutlery company, manufacturing pocket knives, has recently installed Quality Control in its plant. This company has several problems in its control of the manufacture of this product which we wish to present to our members in our January meeting. Representatives of the Management and the Control Department of the cutlery company will be present at our meeting to describe briefly the manufacturing operations and the inspections of the product, and to answer questions.

Problem: Quality Control in a Cutler Company.

1. How would you reduce rejections on knife blades?
2. How may rejections and rework due to "open covers" be reduced?



The tables enclosed in this letter show the weekly percentage of defects at three inspection stations. Clearly certain causes of rejection such as grinding the sides of the blade at Station B and "open covers" at Station No. 6 are the important ones to study, although the overall picture should not be neglected. Our members can contribute most by visualizing as carefully as possible the manufacturing operation connected with each cause of rejection, and by coming to the meeting prepared to discuss with members of the cutlery company, types of corrective action which will reduce the rejection level of the plant.

A sketch of an "exploded" knife from the company catalog shows and labels the parts of a knife. The factory does not always follow this terminology. For example, the factory uses the term "stamping" instead of "brand" and "cover" instead of "handle." "Stagging" refers to the finish shown on the handle or cover of the knife shown in the illustration. An "open cover" will be more fully described in the meeting, but the term refers to the separation of the cover (or handle) from the bolster lining during manufacturing operations, to form an opening or a space. The terms: cover, scale, bolster, pin, and shield, will be used frequently in discussing open covers. The terms: tang, kick, swedge, back, sides and shoulders, will be used in discussing blade inspections.

Please bring this letter to the meeting.

BLADE SAMPLING

WEEKLY PERCENT DEFECTIVE SHEET (#1)—QUALITY STATION B

DEFECT		PERIOD ENDING 1947						
No.	Name	10/27 to 10/31	11/8	11/15	11/22	12/6	12/13	12/20
70	Backs	0.28	0.09	0.92	0.21	0.05	3.64	1.20
71	Swages	0.11	0.06	0.11	1.59	0.12	0.20	0
72	Tang Sides	2.19	1.21	0.61	2.34	1.49	2.27	1.50
73	Sides (Grinding)	5.94	4.83	10.90	5.53	8.96	9.77	9.30
74	Shoulders	2.72	1.77	1.55	2.48	3.42	2.12	3.30
75	Nailmarks	0.11	0.09	0.04	0	0.19	0.35	0.65
76	Stamping	0.54	0.59	0	0.32	0.11	0	0.34
77	Shape	2.29	4.87	14.33	3.34	7.81	2.83	2.09
78	Damage	0.16	0.09	0.44	0.05	0.12	0.31	0.46
83	Buffing	2.40	2.26	2.17	0.86	2.50	1.57	0.64

MATCHING SAMPLING

WEEKLY PERCENT DEFECTIVE SHEET (#1)—QUALITY STATION K

DEFECT		PERIOD ENDING 1947				
No.	Name	11/5 to 11/15	11/22	12/6	12/13	12/20
85	Chipped Covers	1.95	2.13	3.22	1.33	0.86
86	Low Pins	0.04	0.30	1.06	0.04	0
87	Stagging	1.37	5.57	1.15	2.04	2.02
88	High Pins	4.96	5.46	1.37	2.67	2.90
90	Cracked Covers	0.24	0.14	0	0	0.18
91	Short Covers	1.69	1.83	0.73	0.25	0.31
92	Narrow or Wide Cover	2.38	2.19	1.96	0.63	0.87
94	Pin Spinning	4.09	0.39	0.65	3.62	2.66
95	Bad Bolsters or Tips	0.68	1.41	2.41	1.67	2.29
96	Marked Bolsters	2.01	1.24	0.72	0.39	0
97	Glazing	5.83	2.35	3.27	3.23	4.27
98	Shielding	0.15	0.30	0.35	0.04	0.66
99	Open Covers	5.01	3.72	3.65	2.86	3.35

At the meeting, much of the discussion was of necessity technical, and consisted of suggestions for corrective action of manufacturing processes or overcoming production problems. If but one tenth of the suggestions of this nature were suitable for use in this factory, the meeting was successful from the technical viewpoint alone. Of greater importance from the viewpoint of the Program Committee and members of the Syracuse Section, were the recommendations for the improvement of Quality Control in the plant. These served to demonstrate a further application of methods which have proved their value in scores of plants using widely different technical processes.

The recommendations of the members were as follows:

COVERS AND GLUING

WEEKLY PERCENT DEFECTIVE SHEET (#1)—QUALITY STATION NO. 6

DEFECT		PERIOD ENDING 1947	
No.	Name	12/2 to 12/12	12/20
84	Damaged Covers	0.56	0.69
85	Chipped Covers	0.58	0.57
86	Low Pins	0.26	0
87	Stagging	0.54	0
90	Cracked Covers	2.02	2.65
91	Short Covers	1.57	0.74
92	Narrow Covers	0.13	0.05
93	Loose Covers	0.42	0.37
99	Open Covers	20.00	20.83

1. Operators of machines which grind the blades, place the product of their machines in a tray. The last few blades ground are inspected by the operator, who passes or rejects that tray of product. If the product is rejected, the machine is stopped and adjusted. The rejected blades are reworked by other operators—skilled in this specialty operation which is an expensive, hand job.

Recommendation:

(A) Control charts should be kept showing quality of work of each operator of the grinding machines. These charts should be placed so the operator may visualize the quality of his own work.
(B) Sampling of blades should be more representative of the lot in the tray.
(C) The operator should not inspect his own work.
(D) Records of the company seem adequate enough to permit an estimate of rejections due to grinding machines as well as that due to operators. Such an analysis should be made.

2. A discussion of technical details of the manufacturing process indicated a lack of information concerning some characteristics of a few critical raw materials. Control of these characteristics might be essential for maintaining a lower rate of rejection.

Recommendation:
(A) Revision of specifications for purchase of raw materials by the Engineering, Control, and Purchasing Departments with renewed efforts by the Purchasing Department to find sources of materials more suitable for the manufacturing process.
(B) There should be a revision of laboratory tests of raw materials to meet new specifications. Some tests at present may not give the information desired.

3. It was brought out in the discussion that the rejection rate due to one attribute of the assembled knife recently dropped from 20% to about 7% with no assignable cause.

Recommendation:
Analysis of records related to this step should be initiated at once. Though the change in rejection rate was favorable in this case, information concerning the cause of the change will be needed to prevent a reversion of the rate to the former level or higher. This also serves as a test of whether the records of this step in manufacture are adequate for control of the process.

4. It was also emphasized that records in themselves will not lower rejection rates. It is necessary to analyze the data and to act on the information.

This one program (a "clinic" in the sense discussed in the first note of this series) has created good-will and has brought the Syracuse Section several enthusiastic new members. In the Syracuse area there are approximately 25 industries represented by the membership of the Syracuse Section of ASQC. In the same area it is estimated that there are about 100 industries with 100 or more employees. In this latter group there is material for many good "What's your problem" meetings.

The low ratio of ASQC member industries to non-member industries is not peculiar to the Syracuse area. One purpose of this series of "What's your problem" case reports is to demonstrate a method of value to both Membership and Program Committees, in contacting new groups and in showing the value of Quality Control in that group's own plant. If such information can be obtained through local section programs, then ASQC membership will benefit.

A Graphical Method of Determining A Single Sampling Plan

A. R. BURGESS

DEPARTMENT OF MECHANICAL ENGINEERING, WASHINGTON UNIVERSITY

In considering the choice of an inspection plan to be used in the inspection and acceptance of submitted lots, it is now generally recognized that the most important property of such a plan is its operating characteristic, i.e., how the probability of acceptance of a particular plan varies with the fraction defective in the material submitted for inspection. The importance of this operating characteristic is obvious when we recognize the basic purpose of acceptance inspection, that is, to accept good material and reject bad material.

The calculation of the exact probability of acceptance of lots having a stipulated fraction defective when sampled according to a particular plan is quite laborious, especially in the case of the lot which is exhausted appreciably by the withdrawal of a sample. Even in the case where the lot may be considered infinite, the summation of terms of the binomial probability expansion should be used if the sample is small and the fraction defective is large. It has been shown, however, that for samples of the size customarily used in acceptance inspection by attributes, and for practical quality levels in commercial work, say for fraction defective of .10 or less, a satisfactory approximation to the binomial probability formula may be made from the Poisson exponential binomial limit.

The cumulative probability curves for the Poisson exponential are in effect generalized operating characteristics for single sampling. They are in general use for determining the operating characteristics of various sampling plans, both single and multiple, and pro-

vide a ready solution to that problem. It sometimes happens that we desire to devise a new sampling plan, in which we do not know either the sample size or the allowable number of defects, but we do know that we want a plan which will give some pre-determined assurance of acceptance of good material and protection against the acceptance of bad material. The percentage of time that a sampling plan rejects what we have defined as good material has been aptly called by Dodge and Romig [1] the "producer's risk," and conversely the percentage of the time that a plan accepts what we have defined as bad material is known as the "consumer's risk."

In the light of these definitions, we might set up specifications for a plan which would read something like the following: "This sampling inspection plan shall, on the average, accept lots containing 1% defective material at least 95 times out of 100, but shall reject lots containing 5% defective material at least 90 times out of 100." In such a specification we imply that 1% defective is "good" material, and our producer's risk is then 100-95, or 5 times out of 100, which is 5%. Likewise, 5% is here considered to be "bad" material, and the consumer's risk is then 100-90, or a 10% risk of accepting bad material.

The selection of a sampling plan, even a single sampling plan, which will meet these requirements, must ordinarily be done on a trial and error basis although the use of the Poisson cumulative probability chart greatly speeds the solution. To use the above case as an example, the solution would be obtained by following the .95 probability of acceptance line to some arbitrarily selected trial value for c, say 2. We read downward from this intersection to a pn of 0.8, and since p is .01, the corresponding n is .8/.01 = 80. Using this same sample size for 5% defective material we get a pn of 80 x .05 = 4.0. When we follow this pn line up to the c = 2 curve, we get a probability of acceptance of .24, which means that this plan has the correct producer's risk but is much too high on the consumer's risk. So we try again, this time letting c = 3 for acceptance, finding pn is 1.35, giving n = 135; for 5% defective pn = 6.75, and consumer's risk is very close to .10. Hence our conditions have been met by this second trial. Often, of course, due to the discreteness of c and n, the desired conditions can be met only approximately.

It is not always easy to arrive at the solution as simply as in the above example since several trial calculations may be required, and for that reason the author has devised a graphical method to give a quicker solution. This method is based on the fact that the pn scale on the chart is logarithmic, so that the linear distance from 1 to 2 is the same as from 2 to 4, or from 4 to 8, and so on. This enables us to cut out an L shaped piece of paper, and along the bottom edge of this L we plot the pn ratio, which is the same wherever we place this scale on the chart. No scale is drawn along the vertical axis of the L.

The use of this simple device in designing a sampling plan is best explained by an example. Suppose we wish to devise a single sampling plan which will accept 2% defective material 99 times out of 100, but will reject 10% defective material at least 90 times out of 100. We first determine the ratio of "bad" fraction defective to "good" fraction defective, referred to by Peach [2] as the "operating ratio," which in this case is .10/.02 = 5. We then set the L on the Poisson cumulative probability chart with the bottom scale edge coinciding with the consumer's risk line, which is 1—.90, or .10 in this example. We then make a pencil mark on the vertical edge which coincides with the required probability of acceptance of "good" material, which in this case is .99. Now we slide the L horizontally until we find a position such that some c curve passes through the point on the vertical scale, and also through or just to the right of the proper ratio number on the horizontal scale. For the example shown, this requirement is met by the c = 5 line. Since pn is 1.8 for the good lots, n = 1.8/.02 = 90.

Once the scale has been made up, it can be used for any consumer's risk by placing the bottom edge on the proper probability of acceptance line, for any producer's risk by marking the vertical edge at the proper point, and for any ratio of "bad" fraction defective to "good" fraction defective. If one doesn't want to go to the trouble of cutting out an L of this type, the same trick can of course be done with transparent tracing paper. It is evident that this method is applicable only to single sampling plans, but it gives a quick means of determining what size single sampling plan is required to give about the same operating characteristic as one of the standard double or other multiple sampling plans, and its simplicity is such that it is believed many designers of sampling plans will find the method advantageous.

REFERENCES

[1] H. F. Dodge and H. G. Romig, **Sampling Inspection Tables, Single and Double Sampling**, John Wiley & Sons, Inc., New York, 1944.

[2] Paul Peach, **An Introduction to Industrial Statistics and Quality Control**, Edwards & Broughton Co., Raleigh, 1947.

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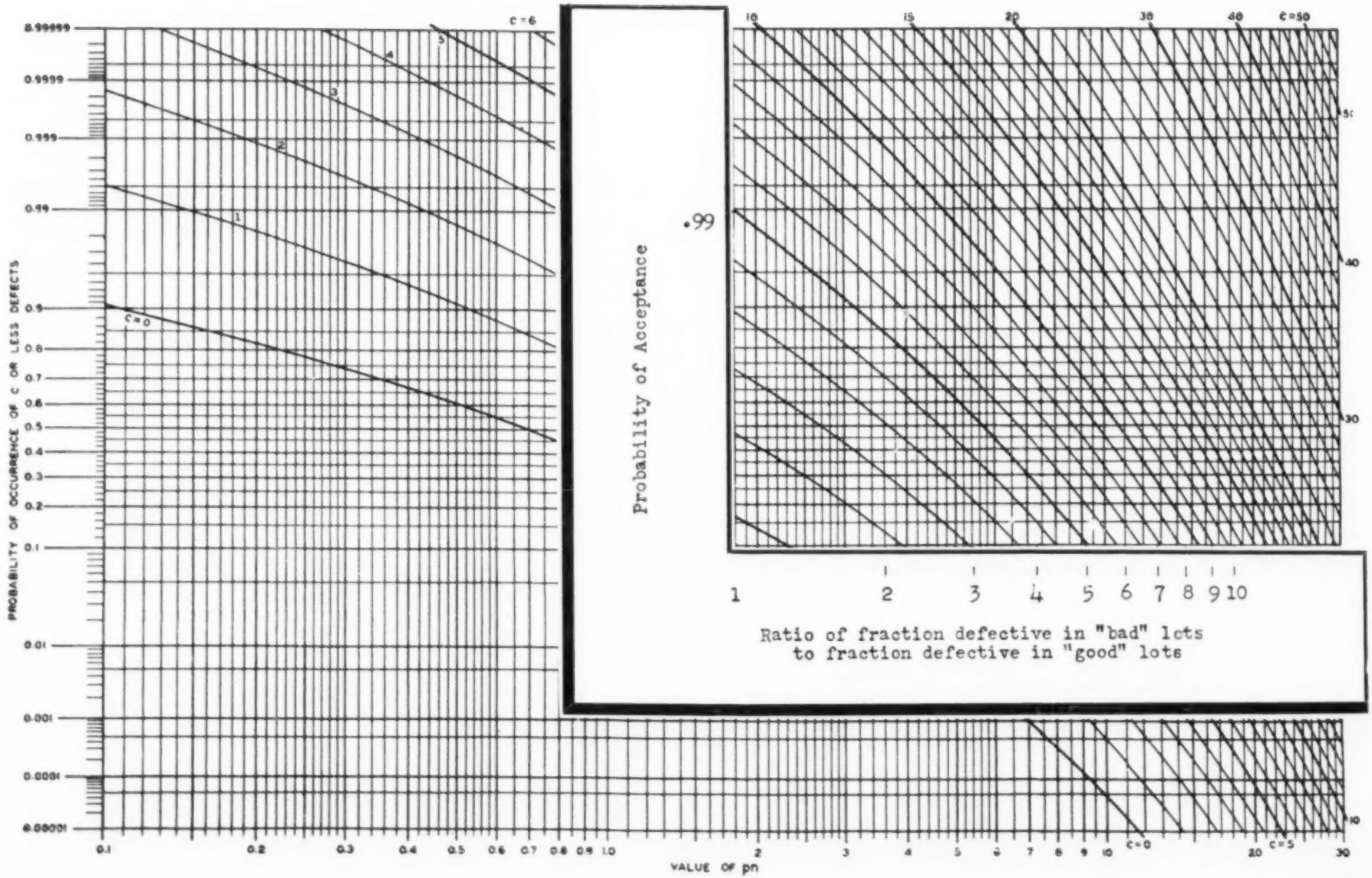

GRAPHICAL SOLUTION OF DETERMINATION OF SINGLE SAMPLING PLAN

Example Shows Plan Which Will Accept 2% Defective Material 99% of the Time, but Accepts 10% Defective only 10% of the time.

(Chart reproduced by permission from "Sampling Inspection Tables," H. F. Dodge and H. G. Romig, John Wiley & Sons, New York City)

ANNOUNCING THE

Third Annual Forum
Michigan Society for Quality Control

FORT SHELBY HOTEL, DETROIT, MICHIGAN
FRIDAY, JUNE 4, 1948, 9 A.M. — 9 P.M.

The Michigan Section of ASQC announces its Third Annual Quality Control Forum to be held in Detroit on June 4, 1948. These one day Forum meetings have helped to meet an expanding demand for knowledge of Statistical Quality Control in the Michigan area. The program for this year's Forum has been planned to further this objective, and thus to make available to industry in this area another opportunity to hear the principles, practices, and applications of this science discussed by recognized leaders in the field.

A registration fee of $10.00 covers charges for attendance at Luncheon, Dinner, and all Forum sessions. Requests for reservations should be directed as follows.

Hotel: Write directly to the Fort Shelby Hotel, Detroit, Michigan.

Forum Sessions: (Including Luncheon and Dinner) Write to:
1948 Quality Control Forum
c/o Moore Products
3175 Penobscot Building
Detroit, Michigan

Miscellaneous: For group table reservations (eight to a table), special arrangements of personal interest, etc. Write to:
Walter S. Oliver
12325 Santa Rosa Drive
Detroit, Michigan

FORUM PROGRAM

9:30 A.M.—Registration.

10:30 A.M.—General Session
SPEAKER: Mr. Warren Jones, Management Controls, Des Plaines, Illinois
SUBJECT: "An Introduction to Quality Control"

12:30 P.M.—Luncheon Session
SPEAKER: Dr. Mason E. Wescott, Chairman of the Editorial Board of **Industrial Quality Control**
SUBJECT: "Across the Country, Industry says 'Quality Control'"

2:30-3:30 P.M.—Two Forum Sessions
SPEAKER: Mr. E. J. McCaulay, Timken Detroit Axle Company, Detroit, Michigan
SUBJECT: "Quality Control at Work in the Receiving Department"
SPEAKER: Mr. Floyd M. Thorman, U. S. Gypsum Company, Chicago, Illinois
SUBJECT: "A Tool for Quality Control — Customer's Complaints"

3:45-4:45 P.M.—Two Forum Sessions
SPEAKER: Mr. R. C. Trombly, Chief Inspector, Hoover Ball and Bearing Company, Ann Arbor, Michigan
SUBJECT: "Quality Control at Work in Fabrication"
SPEAKER: Mr. Leo Harrington, Chief Inspector, King Seeley Corporation, Ann Arbor, Michigan
SUBJECT: "Quality Control at Work in Assembly"

6:30 P.M.—Dinner Session
Professor C. C. Craig, University of Michigan — Introduction of New Officers of the Michigan Section for 1948-49
TOASTMASTER: Mr. B. D. McIntyre, President, Monroe Auto Equipment, Monroe, Michigan
Timken Detroit Axle Company Presents: ? ? ? ? ?
SPEAKER: Mr. L. W. (Larry) Fischer, Vice-President, Timken Detroit Axle Company, Detroit, Michigan
SUBJECT: "Quality Control"

AMERICAN SOCIETY NEWS

NOMINATIONS FOR ASQC OFFICERS 1948-1949

At the meeting of the Executive Committee in December, 1947, President Edwards submitted appointment of the following members to the Nominating Committee:

Elwood E. Folsom, Jr., Chairman
Engineer, Quality Control
General Electric Company
Bridgeport, Connecticut

Ralph A. Hefner
Dean of General Studies
Georgia School of Technology
Atlanta, Georgia

Wyatt H. Lewis
General Electric Co.
Ontario, California

Paul S. Olmstead
Member of Technical Staff
Bell Telephone Laboratories
Murray Hill, New Jersey

Ernest H. Robinson
Director of Quality Control
Johnson & Johnson
Chicago, Illinois

Herbert G. Winter
Monroe Auto Equipment Co.
Monroe, Michigan

All of the above appointments were promptly and unanimously confirmed by the Executive Committee.

Under date of 10 March, 1948, the Chairman of the Nominating Committee transmitted to the Executive Secretary the following slate of nominees unanimously agreed upon by that Committee for Officers of the Society for the fiscal year 1948-1949:

For **President:**

Ralph E. Wareham
Vice-President
National Photocolor Corporation
New York, N. Y.

At present Executive Secretary of the Society

For **Vice-President:**

Wade R. Weaver
Metallurgical Engineer
Republic Steel Corporation
Cleveland, Ohio

At present a Regional Director of the Society.

For **Executive Secretary:**

Simon Collier
Director of Quality Control
Johns-Manville Corporation
New York, N. Y.

At present on the Committee on Professional Ethics and Qualifications of the Society.

For **Treasurer:**

Alfred L. Davis
Associate Director,
Evening Extension Division
Rochester Institute of Technology
Rochester, N. Y.

At present Treasurer of the Society.

Each of the above gentlemen having accepted the nomination tendered by the Committee, their names will appear on the Official Printed Ballot as the Nominees of the Nominating Committee.

No independent nominations for any office having been received by the Executive Secretary prior to 15 April as required by Section **55.** of the Constitution, the above names are the only ones which will appear on the Official Printed Ballot.

ANNUAL MEETING 1948

In accordance with the decision of the Board of Directors at its meeting in February, 1948, under the provisions of Section **60. a.** of the Constitution, the Annual Meeting of the Society will be held in Room 502 at the Engineering Societies Building, 33 West 39th Street, New York, N. Y. at 8:00 P.M. on Thursday evening, 17 June, 1948.

Principal business to come before the meeting will be:

1. Presentation and Acceptance of Annual Reports of the Board of Directors, of the Executive Secretary, and of the Treasurer;
2. Election of Officers for the fiscal year 1948-1949;
3. Any other matters which properly may be brought before the meeting.

Following the business session, Mr. Simon Collier, Director of Quality Control of the Johns-Manville Corporation, will present the Johns-Manville color sound film entitled:

"Modern Quality Control"

It is hoped that arrangements can be made so that those who care to, may have dinner together before the meeting at a restaurant convenient to the Engineering Societies Building.

As provided in Section **60. a.** of the Constitution, formal notice of the Annual Meeting will be mailed by the Executive Secretary before 1 May to every corporate member of the Society. This notice will be accompanied by an Official Ballot for the election of officers, and envelopes for the return of this Ballot as required by Sections **56.** and **57.** of the Constitution.

Each corporate member who cannot attend the Annual Meeting and thus vote in person, is urged:

1. to seal his marked Official Ballot in the plain envelope received with it;
2. thereafter, to seal the plain envelope in the "Official Voting Envelope" received with the Ballot;
3. to sign his name in his own handwriting in the upper left-hand corner of the "Official Voting Envelope;" and
4. to mail the "Official Voting Envelope" to reach the Executive Secretary not later than 17 June, 1948.

By doing this, each corporate member will help to insure that the decisions reached at the Annual Meeting represent the expressed desire of as large proportion of the total membership as possible.

WAIVER OF 1947-1948 DUES

Following the practice inaugurated last year, new members joining the Society after 1 April, 1948 may, if they wish, obtain full paid-up membership through 30 June, 1949 by paying merely the stipulated dues for 1948-1949. This offers new members the opportunity of obtaining as much as 15 months of membership for 12 months' dues.

Such members have the further options however, either of paying one-half of the 1947-1948 dues in addition and receiving all copies of Industrial Quality Control beginning with the January, 1948 issue, or of paying the full dues for 1947-1948 in addition and receiving all copies of Industrial Quality Control beginning with the July, 1947 issue.

YEAR-BOOK 1947-1948

After many delays, the record closing date of 1 May, 1948 was finally set for the 1947-1948 Year-Book. All new memberships and transfers in the hands of the Executive Secretary as of that date will appear in the Year-Book.

In accordance with Section **16.** of the Constitution, the Executive Secretary notified all members delinquent in their dues as of 1 April, 1948, that, in the absence of prompt payment, they would be dropped from membership. In line with this notice, the names of all such members were removed from the list as of 1 May, 1948, and none of these will appear in the forthcoming Year-Book.

All text material for the new Year-Book is now in the hands of the printer, and it is hoped to have it in the mail to all members by mid-June.

MEMBERSHIP RENEWALS AND NEW MEMBERS FOR 1947-48

The Executive Secretary is pleased to report that the response to the appeals of the Membership Committee, and to his own appeals, has been most gratifying. Following his final notice, a very substantial number of members responded with dues payments. The number actually dropped from membership at 1 May, while larger than desirable, was still much smaller than would otherwise have been necessary. In the meantime, a more-than-compensating number of new members have joined the Society. The total membership roll is now substantially in excess of what it was last year at this time, and in fact already approximates the final total as of 30 June, 1947.

ROCHESTER SECTION MAKES SUSTAINING CONTRIBUTION

The Rochester Society for Quality Control has paid to the American Society the sum of $1000, being a portion of the excess of payments by American Society members attending the Rochester Convention, over the actual expenses incurred by the Rochester Society in connection with the Convention.

Recognizing the large extent to which the great interest and effort of the Rochester Section people made this excess possible, the Rochester Society for Quality Control is accordingly being recorded as a Sustaining Contributor to the American Society for 1947-1948.

Guest Editorial -- The Statistical Viewpoint

A. T. CRAIG — THE STATE UNIVERSITY OF IOWA

It is a fact, known to scientists in general and to engineers in particular, that progress in scientific work is usually accomplished through, and attended by, a great amount of experimentation. We recall the history of experiments with falling bodies, experiments in developing new varieties of grain, experiments with new types of explosives, experiments with new drugs, and so on through every aspect of human endeavor in the scientific field. These many experiments terminate with a collection of quantitative or qualitative results familiarly known to us as experimental data.

In certain instances, these experimental data suggest a scientific law which governs the phenomenon under investigation and which makes possible a precise prediction in any given instance. Thus, experiments with falling bodies terminated in what we called the Law of Falling Bodies so that, whenever the conditions of the law are satisfied, we can, under those conditions, predict precisely the velocity of the falling body or the distance traversed at any designated instant of time. Early experimentation in astronomy culminated in our concept of the solar system with the attendant predictability of the positions of the earth and the moon relative to the sun and hence the predictability of solar and lunar eclipses.

On the other hand, many experiments are concerned with phenomena in which no laws such as those just described exist, or, if they exist, have not yet been discovered. For example, in medicine, it is not possible to predict with certainty the outcome of the treatment of a particular patient with a particular drug; in agriculture, it is not possible to predict with certainty the yield of a variety of grain even though temperature, moisture, and other factors which affect yield are rigorously controlled; if one releases a quantity of a certain gas, he is unable to predict the position of a given molecule of the gas at any given time; and in industrial production it is not possible to predict a measurable quality characteristic for a given item of a manufactured product.

There are, then, certain phenomena of such a character that experimentation leads to a law, such that within the framework of the law, prediction with certainty is possible; other phenomena, illustrated by those just mentioned, are of such a character that precise prediction is not possible. It is with this latter class of phenomena that one uses statistical theory and practice, for these phenomena are by their nature susceptible only to some such treatment. Thus we have a statistical theory of gases, a statistical theory of hydrodynamics, a statistical theory of genetics, a statistical theory of longevity (or actuarial mathematics, as it is more frequently called), a statistical theory of the control of the quality of a manufactured product, and so on. We do not, of course, have, in astronomy, a statistical theory of eclipses nor, in classical mechanics, a statistical theory of gravitation. The statistical approach is needed only in those instances in which predictability with certainty is not attainable.

It should prove to be refreshing and stimulating if the user of statistical methods, and particularly the quality control engineer, would pause occasionally and reflect upon the fundamental nature of the work in which he is engaged. Engrossed, as he must be, with the routine necessities of attention to detail in the conduct of his daily duties, he may easily lose sight of the fact that it is not merely **quality control** he is practising, for quality control in one form or another has long been practised. Rather, it is **statistical** quality control that characterizes his profession.

Attainment of the immediate objectives of this profession — improvement of product quality and reduction of production costs — rests, in the last analysis, on the skill and ingenuity exercised by the quality control engineer in wringing from mass data, not prediction with **precision**, but prediction **within limits**. This is the statistical viewpoint; and it is this which distinguishes the activity of the quality control engineer from the level of a job to the level of a science.

Courses in Statistical Quality Control

ILLINOIS COURSE

The Extension Class Division of the University of Illinois is offering its third basic course in Statistical Quality Control from June 8 to June 18, 1948. The course will cover control charts and sampling plans, together with some application to engineering specifications and tolerances.

Enrollment is limited to 50 students from industry and carries no university credits. The tuition will be $100.00 per man, including cost of texts, materials and instruction. Full information about the course may be obtained by writing to Mr. H. C. Rountree, Director of Extension Classes, 118A Illini Hall, 725 S. Wright St., University of Illinois, Champaign, Illinois.

Academic Scholarships

As a new service which should benefit both industry and education, the Extension Class Division is offering up to five academic "scholarships" for this course. Persons engaged in teaching statistical quality control in a bonafide college or university or who plans to teach such courses, may apply to Mr. Rountree. The $100.00 tuition fee will be waived, the students paying only for the actual texts and materials used, and of course, his own travel and sustenance. In case more apply than can be accommodated the extension division will decide on the relative merits of the applicants.

R. I. T. COURSE

An eight-day intensive training course in **Quality Control for the Chemical Industries** will be offered by the Rochester Institute of Technology at Rochester, New York, June 15-23, 1948. While this course will provide instruction in basic statistical control methods, it will also include many of the advanced techniques which are found useful in the chemical industries.

The course is designed for those engaged in analytical laboratory work or for those responsible for controlling quality of product where a continuous production process is involved. The Institute has sponsored three similar courses all of which have emphasized the practical applications of quality control.

The tuition of $100.00 per person includes books and supplies. Room accommodations will be available at the Hotel Rochester. Further inquiries should be addressed to the course coordinator, Alfred L. Davis, Associate Director. Evening and Exchange Division, Rochester Institute of Technology, Rochester 8, New York.

PURDUE COURSE

An eight-day advanced course in statistical quality control will be offered by Purdue University September 9-17 inclusive. This course is intended to meet the needs for additional training of men and women who have had some previous instruction or practical experience in the subject.

Topics to be offered are: review and background of control charts, significance of differences, principles of acceptance sampling, sequential anlaysis, both attributes and measurements, linear and multiple correlation, analysis of variance, tolerances of fitting parts, chi-square, and use of calculating machines.

Prerequisites are a first course or its equivalent. The emphasis will be on applications, and all techniques will be explained as simply as possible.

Tuition is $100. For additional information, write to Professor Irving W. Burr, Department of Mathematics, Purdue University, Lafayette, Indiana.

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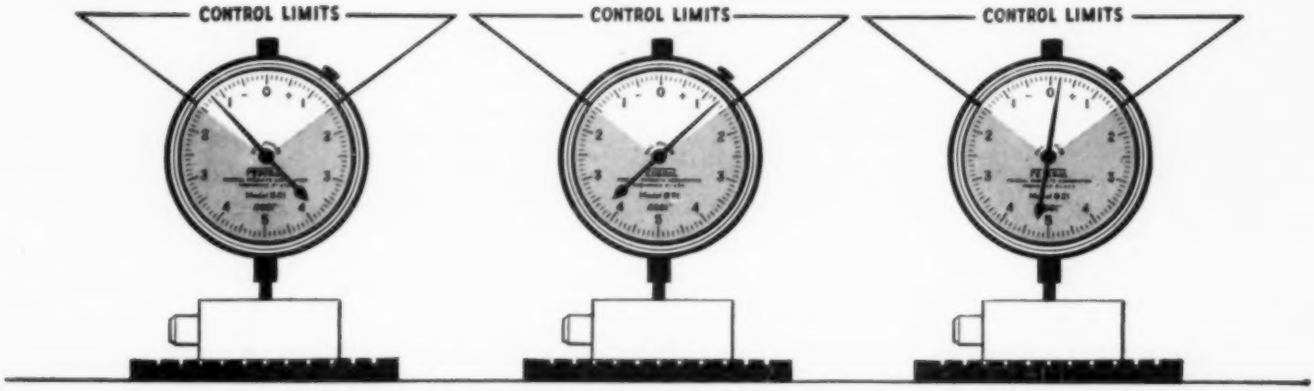

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